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Thermal Response at Room Temperature and Device Applications of Two Wood Species in Akure, South Western Nigeria

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Abstract: Thermal properties (Density, Thermal conductivity and Specific heat capacity) play important impact in the formation of devices made of wooden materials. This study examines the room temperature thermal response of ten bulk samples from the species of *Pterygota macrocarpa* and *Antiaris africana* wood species found in South Western Nigeria. The samples were processed into appropriate shapes to fit into the parallel plane arrangement to determine the thermal properties. Temperature dependent models were used to obtain the specific heat capacities of the samples within a temperature variation of $308.25K$ - $310.00K$. The results revealed that the thermal properties (thermal conductivities and specific heat capacities) increase as temperature increases for all the bulk samples considered. The results of the research showed that the selected wood samples could find useful applications in industrial insulating devices.

Keywords: Wood material, Lee's disc apparatus, Temperature and Thermal properties.

1. INTRODUCTION

The importance of wood and wood products in buildings and other areas of industrial design cannot be overemphasized. Wood is a natural organic composite material that consists of cellulose, hemicelluloses, lignin and extractives, which had been used and adapted by man since the earliest recognition that the material could be utilized for solving basic needs [1, 2]. The performance of wood-frame depends on the thermal properties of wood and wood products [3,4]. Wood is a major material in building and designs whose thermal conductivity is a function of temperature, density, compacting pressure, particle sizes, moisture etc. [5,6]. Information on the thermal conductivity of wood and its relationship to other wood properties is of interest from the standpoint of thermal insulation, drying, plasticizing, preservation, gluing of wood and where heat resistance of wood is a major consideration in its application [7]. Knowledge of physical properties provides a basis for predicting how wood reacts to manufacturing forces and how it will perform in service. Some of the physical properties include; density, thermal conductivity, specific heat, particle size, porosity etc. [8]. Determination of thermal properties from wood based materials depend on several factors such as; Material structure, size, porosity, moisture content, density, the presence of a defect, temperature, and pressure etc. [9,10]. The flow of heat through wood sample is often a measure of the thermal properties.

This present research, however, is aimed at investigating the thermal response at room temperature and device applications of two wood species in Akure, South Western Nigeria

2. MATERIALS AND EXPERIMENTAL PROCEDURE

Two different wood species of the families of *Moraceae and Sterculiaceae* found in the rainforest region, South Western Nigeria were used in this study. These wood samples were cut into circular shape with circular saw machine. The thermal conductivities of the sample were determined using Lee's disc method.

Details of the procedure can be found in the literatures [6, 10] and [11 – 14]. The Thermal Conductivity (λ) of each sample of thickness (d) and radius (r) were estimated using the following equations;

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

where e is given by:

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

where a_A, a_B, a_C and a_S are the exposed surface areas of discs A, B, C and the wood sample respectively. T_A, T_B and T_C are the temperatures of the discs A, B and C above ambient. V is the potential difference across the heater and I is the current which flows through it.

2.2 Determination of Density

The density of a substance is its mass (m_w) per unit volume (v_w). Mathematically, density is defined as

$$\rho_w = \frac{m_w}{v_w} \quad (3)$$

Table 1: Physical Properties of *Pterygota macrocarpa* (Bulk wood)

Temperature K	Density Kgm^{-3}	Thermal Conductivity $Wm^{-1}K^{-1}$	SHC Simpson (Method) $kJkg^{-1}K^{-1}$	SHC Koch (Method) $kJkg^{-1}K^{-1}$
308.25	403.7	0.3351	1.2951	1.2651
308.50	411.1	0.3398	1.2961	1.2662
309.00	405.1	0.3442	1.2980	1.2684
309.50	468.1	0.3468	1.2999	1.2706
309.75	451.1	0.3588	1.3009	1.2717

Table 2: Physical Properties of *Antiaris africana* (Bulk wood)

Temperature K	Density Kgm^{-3}	Thermal Conductivity $Wm^{-1}K^{-1}$	SHC Simpson (Method) $kJkg^{-1}K^{-1}$	SHC Koch (Method) $kJkg^{-1}K^{-1}$
308.50	435.2	0.3459	1.2961	1.2662
308.75	423.6	0.3460	1.2970	1.2673
309.25	395.1	0.3562	1.2990	1.2695
309.75	391.6	0.3580	1.3009	1.2717
310.00	396.5	0.3602	1.3019	1.2728

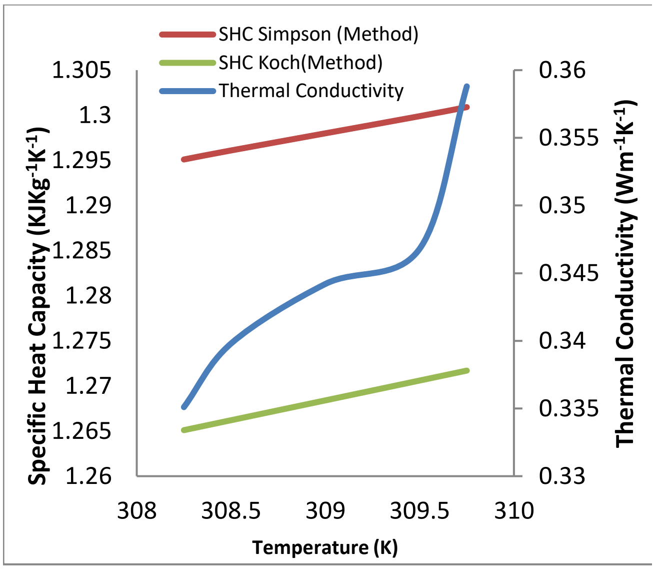

Fig. 1 Graph of Specific Heat Capacity ($kJkg^{-1}K^{-1}$) and Thermal Conductivity ($Wm^{-1}K^{-1}$) against Temperature (K) for *Pterygota macrocarpa*

where mass (m_w) and density (ρ_w) of the wood samples were measured using digital weighing balance and weighing displacement methods [15,16].

2.3 Determination of Specific Heat Capacity

The specific heat of wood changes as volatiles leaves the particle and the particle temperature increases. The specific heat capacity of wood depends on the temperature and moisture content of the wood, but is practically independent of density and species. Two different models were used to determine the specific heat capacity of the bulk wood samples. The approximate specific heat capacity of oven-dry wood c ($kJkg^{-1}K^{-1}$) as a function of temperature $T(K)$ is given by Simpson and Tenwolde [17] as

$$c_w = 0.1031 + 0.003867T \quad (4)$$

Koch (1969) also provided a relation for the specific heat capacity at a temperature range between 333-413K as

$$c_w = 0.2651 + 0.001004T \quad (5)$$

Equation (5) was modified by Grønli [8] to accommodate lower temperatures (i.e. 298 -413 K). The resulting relation becomes,

$$c_w = -0.0912 + 0.0044T \quad (6)$$

where T is equilibrium temperature.

The temperature range in the present study falls within 298 – 413 K, hence, equation (6) was adopted to estimate the specific heat capacity of the bulk sample.

3. RESULTS AND DISCUSSION

The results of the analysis are presented in Tables 1-2. The thermal conductivities values for all the wood species considered increase as the temperatures increase in Figure 1 and 2. This is in agreement with Gupta *et al.* [18] on the Specific heat and thermal conductivity of softwood bark and softwood char particles. The thermal conductivities increase with increase in specific heat capacities for the bulk samples which conforms with Hankalin, *et al.* [5] on the thermal properties of a pyrolysing wood particle. The specific heat capacities of the bulks wood increase as the temperature increases (i.e. specific heat capacities of the bulk wood are temperature dependent) which is in agreement with Simpson and Tenwolde [17] on the physical properties and moisture relations of wood. The results obtained are comparable to that Kärkkäinen [19] for an absolutely dry wood at temperature ranges of 273 K – 373 K. In Figure 3, density of the bulk samples increases with an increase with specific heat capacity between the ranges of 403.7 Kgm^{-3} – 405.1 Kgm^{-3}. There is sharp drop on the value of the specific heat capacity at 411.1 Kgm^{-3}. However, in Figure 4, density increases with an increase in specific heat capacity between the ranges of 391.6 Kgm^{-3}-396.5 Kgm^{-3} before it later increases with decrease in specific heat capacity.

Previous researches had also suggested that the specific heat capacity of wood has no practical dependence on density and species [10, 17].

Comparing the result with the thermal insulation property of some commonly used materials for photovoltaic layer properties which ranges between 0.2148$Wm^{-1}K^{-1}$-148$Wm^{-1}K^{-1}$, all the values obtained were found to fall

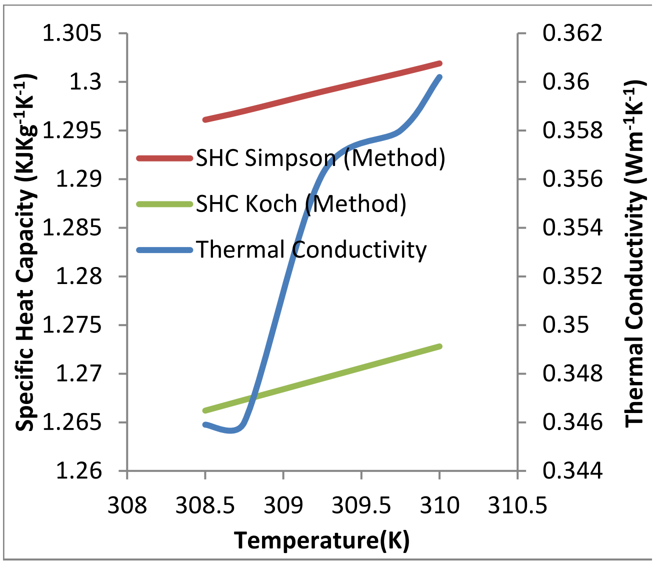

Fig. 2 Graph of Specific Heat Capacity ($\boldsymbol{kJkg^{-1}K^{-1}}$) and Thermal Conductivity ($Wm^{-1}K^{-1}$) against Temperature (K) for *Antiaris africana*

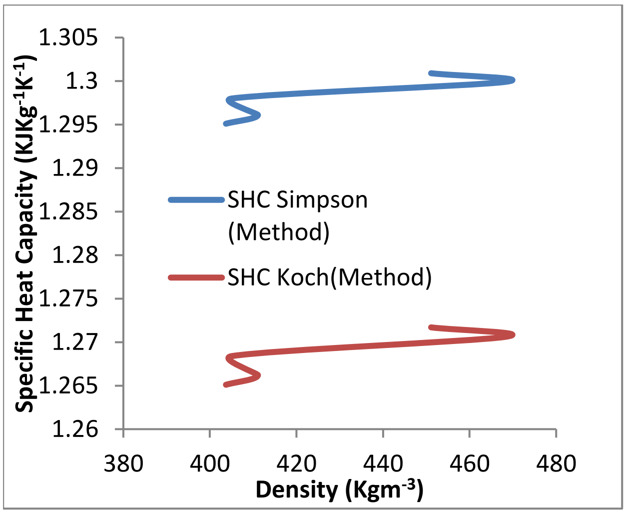

Fig. 3. Graph of Specific Heat Capacity ($\boldsymbol{kJkg^{-1}K^{-1}}$) against Density ($Kgm^{-3}$) for *Pterygota macrocarpa*

within the established properties [20,21]. Hence, the materials can be utilized as thermal insulators in electronics and thermoelectric devices.

4. CONCLUSION

It was established in the research that temperature played significant role when considering thermal properties of wood materials. Thermal conductivity of wood samples increases with increase in temperature. The conductivity is directly proportional to the specific heat capacity of the bulk sample. Within the limit of this research, the thermal conductivities of the samples were found to be comparable to that of the materials used as industrial insulators. Hence,

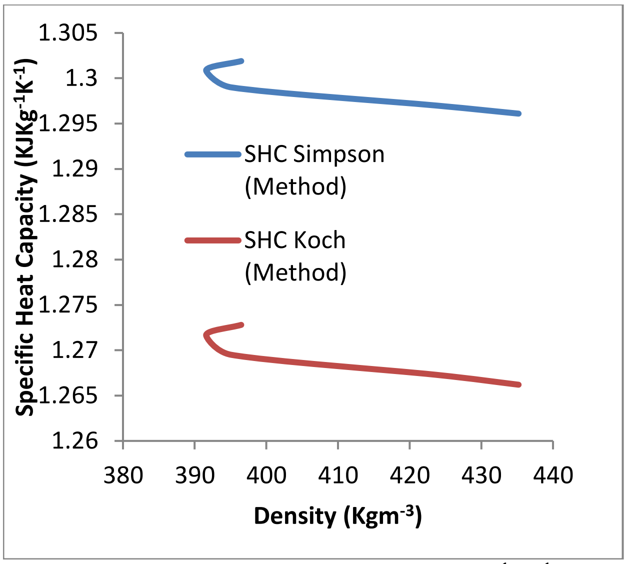

Fig. 4. Graph of Specific Heat Capacity ($\boldsymbol{kJkg^{-1}K^{-1}}$) against Density ($Kgm^{-3}$) for *Antiaris africana*

they could serve as useful materials in industrial insulating devices.

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