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Thermal capacity as a function of moisture content of Sri Lankan wood species: Wheatstone bridge method

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ABSTRACT

This paper describes the variation of thermal capacity of Sri Lankan wood species namely, Attoniya, Pine, Halmilla, Ginisapu and Rubber as a function of moisture content of wood. For this purpose, experimental method was designed and implemented, where wooden blocks of cuboid shape with dimensions of length (6.00 ± 0.05) cm, width (6.00 ± 0.05) cm and thickness (2.10 ± 0.05) cm of each type were heated using a plane electrical heater with dimensions of length (5.00 ± 0.05) cm, width (5.00 ± 0.05) cm and thickness (0.40± 0.05) cm by inserting it into a slit pierced in the blocks. Wheatstone bridge (consisting of two thermistors) was used to monitor the temperature change of the wood samples. Temperature values were digitized and were recorded in a computer via RS232 communication using PIC16F877A microcontroller. The calculated values of specific heat capacity of dry wood was (1.36 ± 0.01) x 10^3 J K^{-1} kg^{-1}, and that for 5%, 10% and 15% moisture content of wood were (1.48 ± 0.02) x 10^3 J K^{-1} kg^{-1}, (1.72 ± 0.02) x 10^3 J K^{-1} kg^{-1} and (1.90 ± 0.03) x 10^3 respectively.

1 INTRODUCTION

Thermal capacity is one of the important thermo-physical properties of matter. In building design, it is equivalent to the thermal mass, a concept used to describe how the mass of the building provides a resistance against temperature fluctuations. Therefore, thermal mass of wood or thermal capacity of wood determines how well buildings which are built in wood would absorb, store and release heat [1].

Calorimetry is the conventional method that is used to measure specific heat capacities of good heat conducting solids such as metals. In this method, the specific heat capacity of a solid (at a higher temperature than water) is determined by immersing it into a calorimeter containing water and by equating the heat gain and loss by water and the solid. [2]. Calorimetric methods are also used to measure heat capacities of bad heat conducting solids such as rubber which do not absorb water using the cooling correction method [2–3]. Since the specific heat capacity of wood depends on temperature as well as the moisture content of wood, calorimetric methods are not suitable for this purpose.

A standard method to find thermal capacity of insulators is the transient plane source method [4–5]. In this method, hot disk is used for both heating and temperature sensing process of samples of which the thermal capacity is measured. This hot disk contains very thin nickel coil and caption layer. However it is a very expensive instrument and therefore one needs to design and implement an inexpensive low cost method to determine the variation of thermal capacity of insulators. This paper describes Wheatstone bridge method to measure and study the variation of thermal capacity of due to the changes in moisture content of different wood species.

2. METHODOLOGY AND IMPLEMENTATION

2.1 The design and construction of a device to supply heat to wood samples

In this work, five species of Sri Lankan wood namely, Attoniya, Pine, Halmilla, Ginisapu and Rubber were considered. Wooden block samples of cuboid shape with dimensions of length (6.00 ± 0.05) cm, width (6.00 ± 0.05) cm and thickness (2.10 ± 0.05) cm were machined from wooden bars of each species.

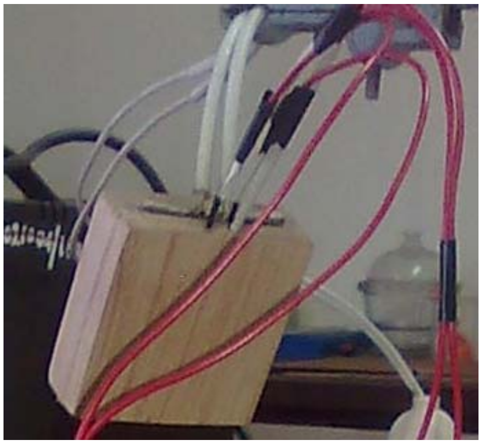
Wood samples were dried in an oven at a temperature of 100 °C for 30 minutes in order to evaporate moisture in the samples and were considered as “dry wood” and the mass of the specimen is referred as “oven-dry mass”. The percentage of moisture content of wood samples of each species were determined considering the oven-dry mass and the initial mass of the wood specimen using equation (1)

$$\text{Moisture content (\%)} = \frac{\text{Initial mass} - \text{Oven-dry mass}}{\text{Oven-dry mass}} \text{x}100 \qquad (1)$$

Oven-dry mass of sample was measured after the drying process and then initial mass was calculated for different moisture levels which are called 5%, 10% and 15% by substituting oven-dry mass for the equation (1). Then water was sprayed to the sample until it reaches the calculated initial mass which corresponds to the particular moisture content required. The mass of the wooden block samples was measured using an electronic balance with an accuracy of ± 0.005 g.

In order to supply thermal energy to samples of wood species, a slit is pierced in wooden blocks and a specially constructed plane heater with dimensions of length (5.00 ± 0.05) cm, width (5.00 ± 0.05) cm and thickness (0.40± 0.05) cm was inserted into the slit as shown in Fig. 1(A). The rate of thermal energy (power) supplied to wood samples by the plane electrical heater was 40 W. Two holes were created in the block in order to insert the sensing elements of thermistors, Fig. 1 (A).

Wooden block sample was mounted on a base that was made by sharpened wooden tooth-picks and whole setup was covered by vacuumed glass chamber to minimize radiation heat loss, Fig. 1 (B).



(A)

(B)

Fig 1 (A) A plane heater inserted into a wood sample of cuboid shape. The sensing elements of thermistors are inside the wooden block (B) Wood sample mounted on base and covered by vacuumed glass chamber to minimize radiation heat loss

2.2 Temperature measurements using the Wheatstone bridge

The thermistors each of resistance R_T and two fixed resistors R were connected in opposite arms configuration to a Wheatstone Bridge with a d.c. supply voltage of U_0 to measure the temperature rise of the wood samples (Fig. 2).

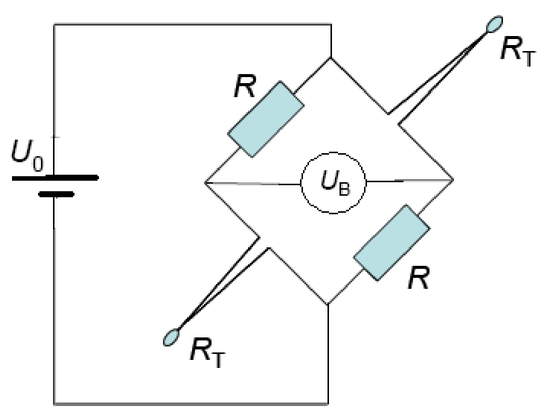


Fig. 2 Schematic diagram of Wheatstone bridge circuit to measure thermal capacity of wood

The output signal U_B of the Wheatstone bridge is given by equation (2)

$$U_B = \left(\frac{R}{R_T + R} - \frac{R_T}{R + R_T} \right) U_0 \qquad (2)$$

Since the resistance R_T is a function of temperature the output signal U_B of the Wheatstone bridge is also a function of temperature. A stable d.c. voltage supply was needed for the Wheatstone bridge. The amplitude of the supply voltage to the Wheatstone bridge was chosen around 2 V, to reduce self-heating of thermistors.

The output signal of the Wheatstone bridge was connected to PIC 16F877A microcontroller. PIC microcontroller was programmed to perform analog to digital conversion and therefore it acts as an Analogue to Digital Converter (ADC). The digital values of ADC were transmitted to the personal computer (PC), through the RS232 communication using serial port and displayed on the terminal window of the PC. The Fig. 3 illustrates this procedure in a block diagram. The MAX232 IC was used to converts signals from TTL compatible digital logic circuits to signals suitable for use in an RS-232 serial port.

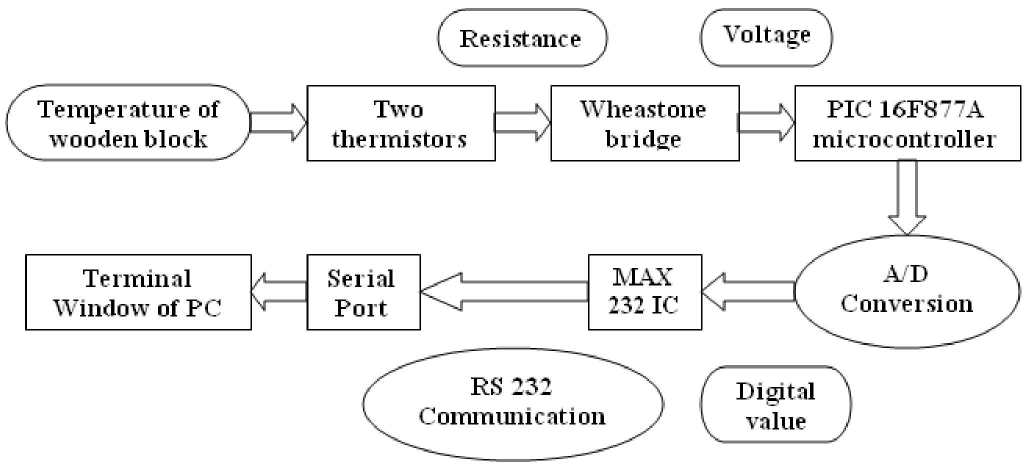


Fig 3 Block diagram illustrating of temperature measurement using Wheatstone bridge method

Initially, the Wheatstone bridge assembly was calibrated against the Hg thermometer. Here the two thermistors were placed in the calorimeter containing water at room temperature and was heated. Hg thermometer was placed in the calorimeter to measure the temperature of water. The calibration curve for the two thermistors which are connected to Wheatstone bridge was determined experimentally and is given by equation (3). The temperature T is found to have a root mean square error of ± 0.7705

$$T = 27.83 \text{ x } \exp(0.003871V) \qquad (3)$$

2.3 Experimental Procedure

With the heater switched on, a given wooden sample was heated to a maximum duration of 40 s. The microcontroller was programmed to display corresponding digital value for the temperature of the sample at every one second time interval during the heating process. Actual temperature values (T) of wood samples after the 40 s period of heating process were calculated using the calibration curve of the two thermistors using the Equation 3. The temperature change (ΔT) within the 40 s time interval was calculated from the difference between final temperature (T) and initial temperature (room temperature). Knowing ΔT values and measuring mass of a given wooden sample, the specific heat capacity of wood samples were calculated. Three wooden block samples of each wood species were used in experiments in order to improve the accuracy of measurements.

3. RESULTS AND DISCUSSION

The average mass of dry wooden block samples of Attoniya, Pine, Halmilla, Ginisapu and Rubber were 52.9 ± 0.9 g, 49.8 ± 0.5 g, 59.58 ± 0.07 g, 42.3 ± 0.3 g and 43.2 ± 0.3 g respectively and the temperature ranges observed when a constant heat of 1600 J was supplied were 23.1 ± 0.5 K, 23.5 ± 0.5 K, 20.7 ± 0.5 K, 27.4 ± 0.5 K and 26.8 ± 0.5 K respectively.

Table 1 show the experimentally determined specific heat capacity values of given wood species for dry wood and wood with different moisture content levels. The Fig. 4 shows the variation of specific heat capacity values of given wood specie for dry wood and wood with different moisture content levels.

Table 1: Specific heat capacity of dry wood and wood with different moisture content levels

Wood Species	Specific heat capacity ($J\ K^{-1}\ kg^{-1}$) x 10^3			
	Dry wood	Moisture content		
		5%	10%	15%
Attoniya	1.313 ± 0.030	1.456 ± 0.038	1.694 ± 0.055	1.873 ± 0.070
Pine	1.365 ± 0.037	1.473 ± 0.037	1.732 ± 0.054	1.918 ± 0.069
Halmilla	1.338 ± 0.035	1.469 ± 0.044	1.715 ± 0.064	1.894 ± 0.081
Ginisapu	1.380 ± 0.026	1.490 ± 0.032	1.736 ± 0.045	1.929 ± 0.060
Rubber	1.382 ± 0.027	1.499 ± 0.033	1.724 ± 0.047	1.921 ± 0.060

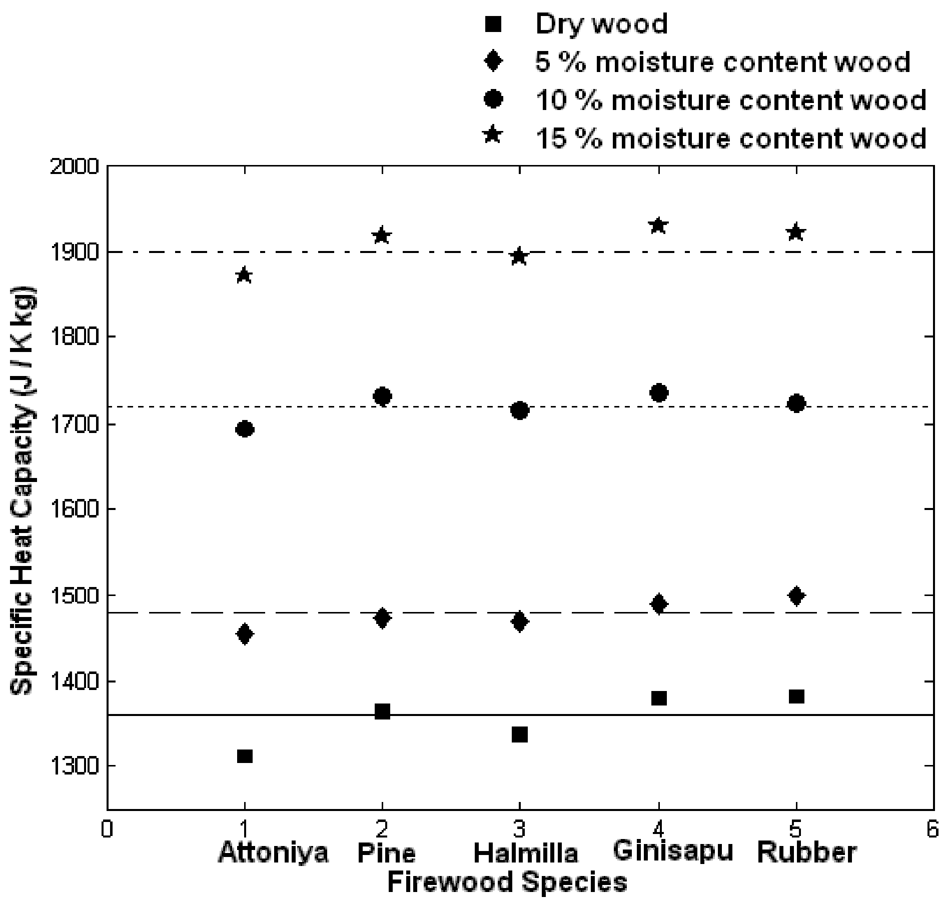


Fig. 4 Variation of specific heat capacity of wood species for dry wood and for wood with different moisture content levels

According to Table 1 and Fig. 4, it can be seen that the variation of specific heat capacity of dry wood for different wood species is negligible considering errors of specific heat capacity values. For given moisture content level, there is a slight deviation among specific heat capacity values of different wood species but this deviation is very small compared to the values of specific heat capacity of each type and then it can be neglected. Accordingly specific heat capacity of different fire wood species with different moisture content is approximately equal. That is, the specific heat capacity remains constant for given moisture content level. Therefore it can be said that the specific heat capacity of wood is independent on the species. These results confirm the already documented observations by Simpson and TenWolde that the specific heat capacity of wood depends on the moisture content of the wood, but is practically independent of density and species [6].

Since specific heat capacity is independent on the type of species, it is possible to assign a mean value for specific heat capacity of dry wood and wood with a particular moisture content level (Table 2).

Table 2: Specific heat capacity values for dry wood and wood with different moisture content levels

Moisture content level (%)	Specific heat capacity (C) ($J\ K^{-1}\ kg^{-1}$)
Dry Wood	$(1.36 \pm 0.01) \times 10^3$
5 %	$(1.48 \pm 0.02) \times 10^3$
10%	$(1.72 \pm 0.02) \times 10^3$
15%	$(1.90 \pm 0.03) \times 10^3$

The Fig. 5 illustrates the specific heat capacity variation according to the moisture content of wood.

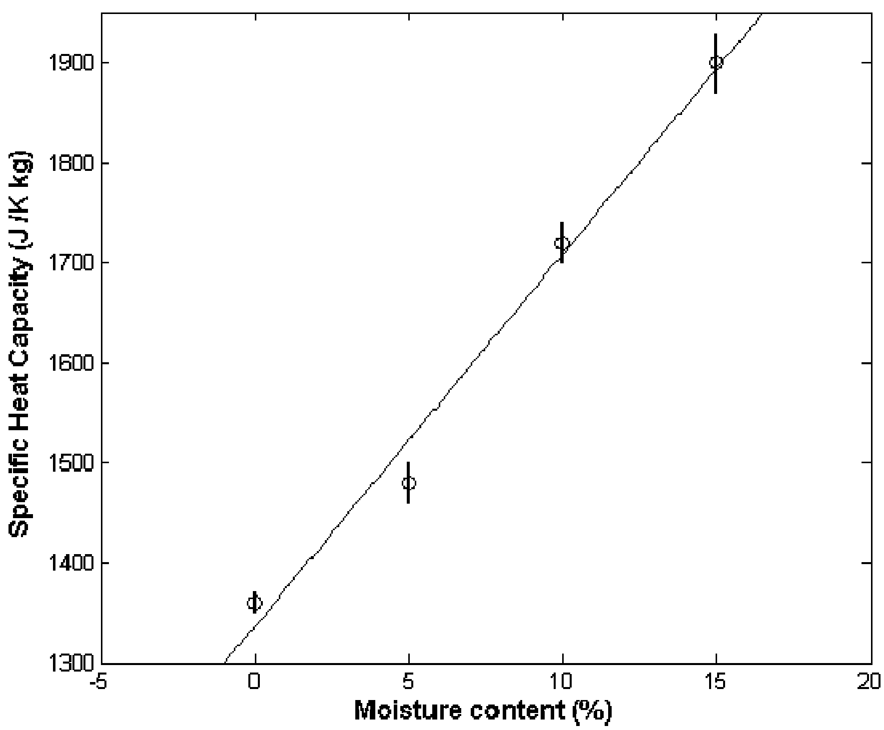


Fig. 5: Relationship between Specific heat capacity and moisture content

The specific heat capacity of wood that contains water is greater than that of dry wood. The specific heat capacity *C* and moisture content follows a linear relationship given by equation 4

$$C = 37.2\ M + 1.34 \times 10^3 \quad (4)$$

(where *M* is the moisture content given as a percentage value of wood.)

The equation 4 is valid for only the moisture content below fiber saturation point (moisture content below 20% or 25%) [6].

4. CONCLUSION

An experimental method has been developed successfully to measure and study the variation of specific heat capacity as a function of moisture content of different wood species available in Sri Lanka.

It can be concluded that the specific heat capacity of wood materials increases with moisture content level of wood but are practically independent of wood species agreeing with previously published results [6].

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