COMPUTATIONAL ANALYSIS OF HEAT CONDUCTION IN NANOWOOD COMPOSITE BOARDS

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Report submitted in partial fulfilment of the requirements
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Position: PROFESSOR
Date: 13 JUNE 2012

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ID Number: MA09008
Date: 13 JUNE 2012

Dedicated to my beloved parents

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ABSTRACT

This project deals with the investigation of heat transfer problem or specifically heat conduction problem through wood-based material. The objectives of this project are to determine the thermal conductivity of nanowood composite boards having different particle concentrations and to investigate heat conduction problem of wood composites. The thesis describes the proper manufacturing process of Medium Density Fiberboard (MDF) in order to investigate the thermal properties and mechanical properties wood-based material. The nanoparticle was used as the raw material to produce MDF. The studies of mechanical properties that are involved in this project consist of hardness of the MDF. For thermal properties of MDFs, we observed the thermal conductivity, thermal resistivity, thermal diffusivity and specific heat capacity of them using KD2 Pro apparatus. As for the recommendation, the thermal properties should be considered in order to optimally select a material for its specific application.

ABSTRAK

Projek ini adalah berkaitan dengan penyiasatan masalah pemindahan haba atau khususnya adalah masalah konduksi haba melalui bahan berasaskan kayu. Objektif projek ini adalah untuk menentukan kekonduksian terma papan komposit nano yang mempunyai kepekatan zarah yang berbeza dan untuk menyiasat masalah konduksi haba komposit kayu. Justeru, tesis ini menerangkan tentang proses pembuatan papan gentian Ketumpatan Sederhana (MDF) di mana ia bertujuan untuk menyiasat sifat-sifat terma dan sifat-sifat mekanik bahan yang berasaskan kayu tersebut. Zarah nano telah digunakan sebagai bahan mentah untuk menghasilkan MDF. Kajian sifat-sifat mekanik yang terlibat dalam projek ini terdiri daripada kekerasan MDF. Bagi sifat haba MDF, kami memerhatikan keberaliran haba, kerintangan haba, kemeresapan haba dan muatan haba tentu mereka menggunakan radas KD2 Pro. Sebagai cadangan pada masa hadapan, sifat haba perlu dipertimbangkan untuk memilih satu bahan untuk aplikasi khusus secara optimum.

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

This study is about the analysis of heat conductive in nanowood composite boards. In Malaysia, wood composite industry is one of the biggest industrial sectors as well as around the world. Many new products have been developed since the 1960's, such as medium density fiber board (MDF), wafer board, oriented strand board (OSB) and some cement bonded boards. The pressing operation is one of the most important and expensive in the manufacture of these products. A quantitative understanding of it is important if we are to improve the performance of existing products, to reduce pressing times, and to design processes for the manufacture of new products with specified properties (Humphrey, 1989).

The modeling of hot-pressing relies on a rigorous understanding of many interactive physical processes, one of which is conductive heat transfer. The slow heat transfer due to low thermal conductivity of wood particles is one of the major concerns. Because of that, many different ways were developed such as steam injection and high platen temperature are being tried to increase the heat transfer. One more innovative method is to use nanoparticles such as aluminum oxide, copper oxide and ferrous oxide in small percentage mixed with the thermosetting resin and added in the wood particles.

In nanotechnology, a particle is defined as a small object that behaves as a whole unit in terms of its transport and properties. Particles are further classified according to size in terms of diameter; coarse particles cover a range between 10,000 and 2,500 nanometers. Fine particles are sized between 2,500 and 100 nanometers. Ultrafine particles or nanoparticles are sized between 100 and 1 nanometers. In this study, the rule of mixtures will be employed to predict the properties of the nanowood composite material. The thermal conductivity of nanowood composite boards having different particle concentrations will be experimentally evaluated.

During composite manufacture, heat energy is transferred from hot platens to the composite both by conduction and by convection of water vapor (following phase change). At high temperature and in the presence of moisture, wood materials become soft and are easily compacted by pressing pressure to form high density board. In the meantime, the adhesive is cured to achieve strong internal bond strength.

1.2 PROBLEM STATEMENT

From this study, the problem of heat conduction in a solid slab will be numerically solved and compared with solutions obtained from software for wood fibre boards and nanowood composite boards. Comparison is made between the experimental results and computational predictions. Later, reasons for any deviations will be analysed.

1.3 PROJECT OBJECTIVES

i. To determine the thermal conductivity of nanowood composite boards having different particle concentrations.
ii. To investigate heat conduction problem of wood composites.

1.4 SCOPES

The scopes of this project are:

i. Learning the use of software available in the Faculty/Department.
ii. Formulating a mathematical model for the problem through software and analytically.
iii. Experimental determination of thermal conductivity of nanowood composites.
iv. Comparison of numerical values with experimental results.

1.5 OVERVIEW OF REPORT

Chapter 1 mainly briefs about the background of the project which involves the introduction, problem statements, objectives and scopes of the report. Chapter 2 basically describes more about the studies on heat conduction process of wood composites and wood-based composites which has been done earlier by other scientists. Whereas Chapter 3 introduces the experimental procedures and other methods of this project. Chapter 4 is discussed about result of the whole project and Chapter 5 is about the conclusion that can be made and also the future recommendations in this heat transfer matters.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, it is basically describes more about the studies on wood composite and wood-based composite material which has been done earlier by other investigators. Therefore, it is also discussed about the heat conduction process on hygroscopic material which has been used in this experiment.

2.2 HEAT TRANSFER

Heat transfer is a discipline of thermal engineering that concerns the exchange of thermal energy between physical systems. Heat transfer is classified into various mechanisms, such as heat conduction, convection and thermal radiation. Engineers also consider the transfer of mass of differing chemical species, either cold or hot, to achieve heat transfer. While these mechanisms have distinct characteristics, they often occur simultaneously in the same system. Conduction or diffusion is the transfer of energy between objects that are in physical contact. Convection is the transfer of energy between an object and its environment, due to fluid motion while radiation is the transfer of energy to or from a body by means of the emission or absorption of electromagnetic radiation. On the other side, mass transfer is the transfer of energy from one location to another as a side effect of physically moving an object containing that energy.

Wood is a porous and hygroscopic material consisting of a combination of solid substance (cell wall) and air pockets (voids). Heat transfer through solid is by conduction. Heat transfer through the voids of moist wood is essentially by vapor convection, especially at relatively high temperatures. Radiation may only play a significant role when heat is transferred through the voids of dry materials under extreme conditions. Wood and wood-based materials, then, offer resistance to heat flow because of the small air pockets in them, as well as the resistance of the wood substance itself to heat transfer (Lawie, 1967).

It is very important to be aware of the confluence of the various mechanisms of heat transfer because, in practice, when one mechanism dominates, approximate solutions are obtained by neglecting all but the dominant mechanism. However, a change of external conditions will often require that one or both of the previously neglected mechanisms be taken into account. For example, when wood and wood based composites are used as building materials in the atmosphere, heat flows mainly by conduction. When pressing wood-based composites, both conduction and convection (even radiation) become significant.

2.3 CONDUCTIVE HEAT TRANSFER

2.3.1 Thermal Conductivity

Conductive is a process of heat transfer by means of molecular agitation within a material without any motion of the material as a whole. If one end of a metal rod is at a higher temperature, then energy will be transferred down the rod toward the colder end because the higher speed particles will collide with the slower ones with a net transfer of energy to the slower ones.

In the solution of heat conduction problems, it is necessary to determine whether a process is of the steady- or unsteady-state type. When the rate of heat flow in a system does not vary with time, the temperature at any point does not change and steady-state condition prevails. Under steady-state conditions, the rate of heat input at any point of the system must be exactly equal to the rate of heat loss, and no change in internal energy can take place (Frank, 1958). It is often takes a long time for a system to attain such a steady-state condition. When the temperatures at various points in a system change with time, the heat flow is transient, or unsteady. Such heat flow problems are encountered during warm-up or cool-down periods.

Fourier's Law of heat conduction is presented as:

$$q = - k.A(dT/dx) \tag{2.1}$$

where q = rate of heat flow
k = thermal conductivity of the material
A = the area of the section through which heat flows (perpendicular to the direction of heat flow)
dT/dx = temperature gradient at the section

The thermal conductivity (K) is the energy (Q) per unit time (t) which flows through a thickness (x) of a substance with a surface area (A) under a steady-state temperature difference between faces of T1 and T2 (Kollmann, 1968). Thermal conductivity that will be used in this project is in the International Standard (SI) unit --- watts per meter per Kelvin (W. / m.K).

2.3.2 Thermal Diffusivity

Thermal diffusivity (a) is used to determine the rate of temperature change in a material when it is subjected to a change in ambient temperature (Wangaard, 1969). An analysis of the time-temperature relationship needs a calculation of the diffusivity. In a sense, thermal diffusivity is the measure of thermal inertia (Venkanna, 2010). In a substance with high thermal diffusivity, heat moves rapidly through because the substance conducts heat quickly relative to its volumetric heat capacity or 'thermal bulk'.

The substance generally does not require much energy from its surroundings to reach thermal equilibrium. Thermal diffusivity is often measured with the flash method. It involves heating a cylindrical sample with a short energy pulse at one end and analyzing the temperature change at the other end. An analysis of the time-temperature relationship needs a calculation of the diffusivity.

In heat transfer analysis, thermal diffusivity is the thermal conductivity divided by density and specific heat capacity at constant pressure (David R. 2009). It has the SI unit of m^2/s. The formula is:

$$\alpha = k/c_{p}.\rho \tag{2.2}$$

where: k = thermal conductivity $(W/(m\cdot K))$
ρ = density (kg/m^3)
c_p = specific heat capacity $(J/(kg\cdot K))$

Fourier's heat conduction equation is written as:

$$dT/dt = \alpha\ (\delta^2 T/\ \delta x^2) \tag{2.3}$$

The change of temperature in a homogeneous isotropic body is expressed according to Fourier by the following partial differential equation:

$$dT/dt = \alpha\ (\delta^2T/\ \delta x^2 + \delta^2T/\ \delta y^2 + \delta^2T/\ \delta z^2) \tag{2.4}$$

where: α = thermal diffusivity
t = unit time.

2.3.3 Specific Heat

The specific heat, c, is defined as the quantity of heat required to raise the temperature of unit mass of a substance one degree. In the SI system of units, specific heat is expressed as J.kg'.°C'.

If a quantity of heat (Q) is necessary to raise the temperature of a substance with mass m from Ti to 12, specific heat is expressed as:

$$c = Q/m.(T_2-T_1) \tag{2.5}$$

where: Q = heat energy (J)
m = mass (kg)
T_2,T_1 = temperature (°C)

The specific heat of most materials is temperature dependent. However, temperature is a variable in the definition of specific heat. Therefore, the true specific heat is defined as:

$$c = (1/m)(dQ/dT) \tag{2.6}$$

2.4 METHODS OF MEASURING THERMAL PROPERTIES

2.4.1 Steady-state Methods

a) Thermal Conductivity

There are a number of ways to measure thermal conductivity. Each of these is suitable for a limited range of materials, depending on the thermal properties and the medium temperature. In general, steady-state techniques are useful when the temperature of the material does not change with time. This makes the signal analysis straightforward (steady state implies constant signals). The disadvantage is that a well-engineered experimental setup is usually needed. For good accuracy relatively large temperature gradients are often used (in the order of 40°C). Since materials of low thermal conductivity such as wood-based composite can take a long time to reach steady-state conditions, the measurement process may be very time consuming. Furthermore, for hygroscopic materials such delays can lead to a moisture migration, within the specimen (Gammon, 1987).

Most available data on the thermal conductivity of wood were obtained by the plate method (Wangaard 1969), first used by Grober (1910) and subsequently modified through the introduction of a "guard ring" to eliminate edge losses (Poensgen, 1912). This method was eventually adopted in the development of a standard testing apparatus for insulating materials by the U.S Bureau of Standard (VanDusen, 1920). The standard method given in ASTM C-177 (ASTM, 1980) uses a guarded hot plate to minimize heat loss.

b) Specific Heat

Dunlap (1912) described a method using the Bunsen ice calorimeter. Oven dry wood cylinders just above the boiling point of water were placed in the calorimeter which contained a known volume of ice and water. The calorimeter was packed in ice and held at zero degrees centigrade. Because ice occupies more volume per unit mass than does water, the measurement of volume contraction, caused by the ice melting from the heat given up by the wood, was used as a measure of the heat given up by the wood.

The method used in ASTM C351-61 (ASTM, 1980) involves using an oven-dry sample that is heated in a capsule (1" in diameter and 2" long) to 100°C, and immersed in a flask containing 300 g of distilled water at 20°C. The specific heat of the wood is calculated from the temperature increase of water caused by the heat given up from the wood, which was adjusted for the heat capacity of the calorimeter. The calculated specific heat is the mean of that of the wood over the initial temperature of the sample and the final temperature of the water.

2.4.2 Unsteady-state Methods

The transient techniques perform a measurement during the process of heating up. Their advantage is quicker measurements. But, the most serious problems encountered in the use of unsteady-state, or transient, methods are usually the production of the desired boundary conditions, the evaluation or prevention of unwanted heat losses, and the calculation of results (Clarke, 1953).

a) Vernotte's Method

Vernotte (1937) proposed a method of obtaining the equivalent of a perfect insulator by using a symmetrical arrangement as illustrated in Figure 2.1. The boundary conditions in Figure 2.2 to be satisfied were:

$dT/dx = 0$ at $x = 0$
$dT/dx = Q/K$ at $x = L$ 2.8
$T = O$ at $t = 0$ (2.7)

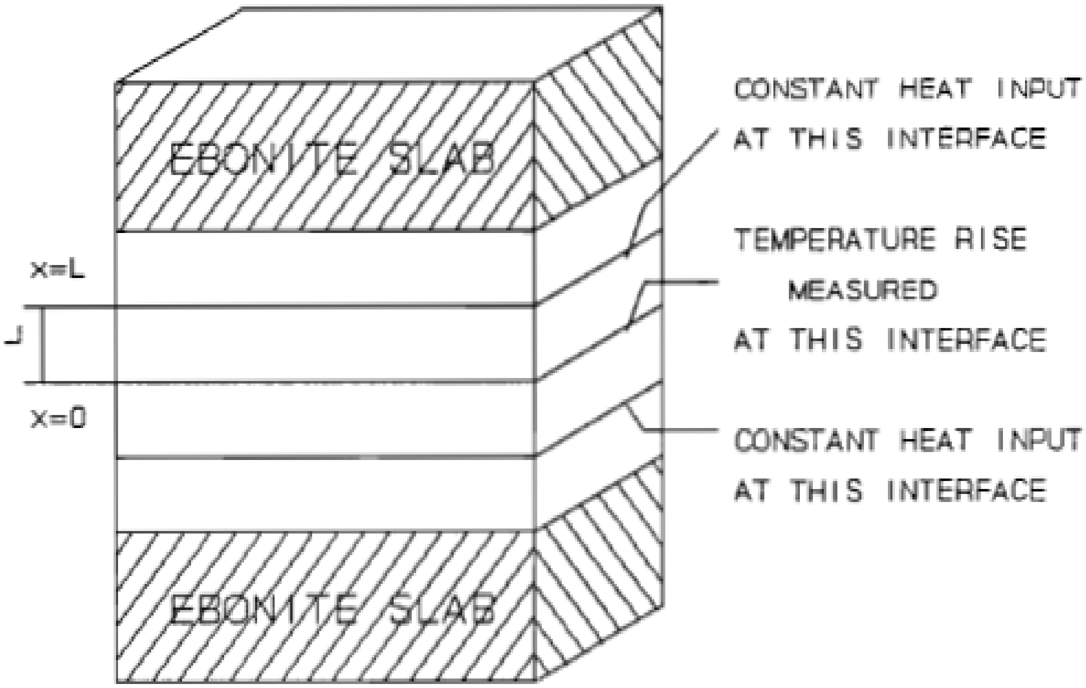

Figure 2.1: Experimental arrangement by Vernotte

Source: Vernotte, 1953

Clarke and Kingston (1950) modified Vernotte's method and developed a new experimental procedure that is set up as shown in Figure 2.2.

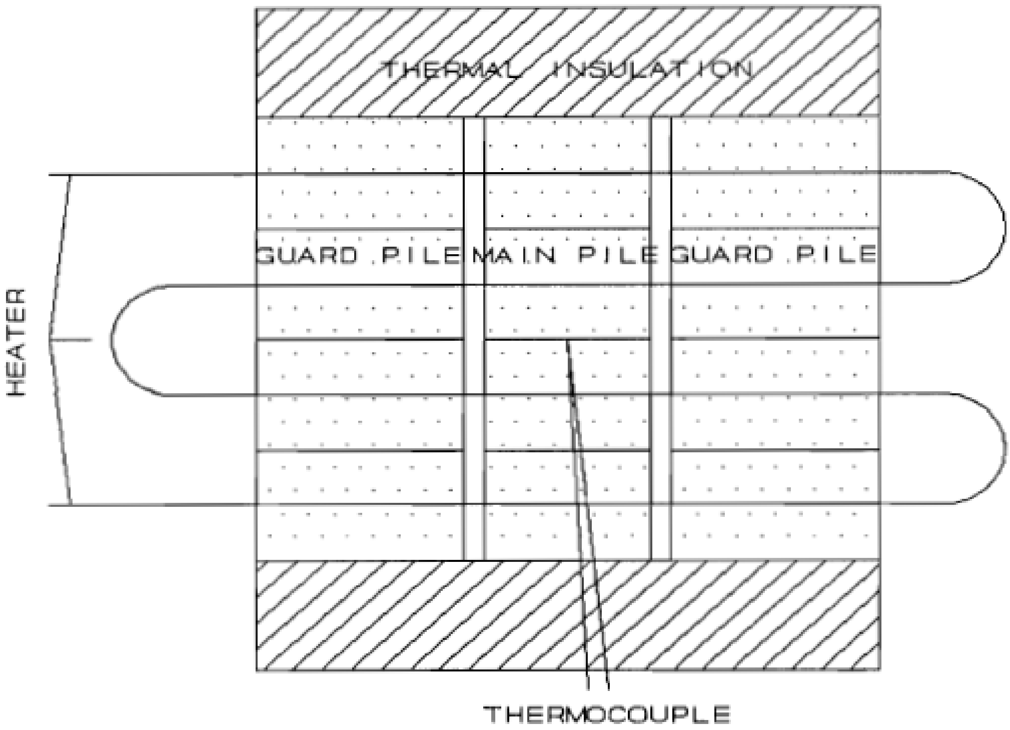

Figure 2.2: Experimental arrangement of piles
Source: Clarke and Kingston, 1950

The boundary conditions of this method were the same as those of Vernotte (1937). Guard piles were used on either side of the main pile to minimize heat loss or gain to the atmosphere. Because the thermal properties of the ebonite or other materials used in the apparatus are comparable with those of the wood being measured. Vernotte's assumption that half of the heat flows towards the thermocouple was erroneous (Clarke and Kingston, 1950).

Parsons (1955) tested Clarke and Kingston's apparatus and found the method suitable to examine the thermal properties of hygroscopic materials. In 15 minute test periods, the temperature gradient across the specimen reached a maximum of 0.2°C/mm. No change in moisture content was detected. Pratt and Ball (1956) used both a steady-state method and Clark and Kingston’s unsteady-state method on samples of particle board, cork and asbestos board. The close agreement of results led them to the conclusion that the unsteady-state method had practical value.

b) Clarke’s Method

Clarke (1954) developed another unsteady-state method to measure the thermal conductivity of poor conductors over a variable temperature range as illustrated in Figure 2.3. Clarke's method differs from the standard steady-state method in two ways. First, the temperature of the test samples is continually changed. Second, the rate of heat movement through the sample is obtained by measurement of the temperature rise of a "heat sink" of known heat capacity rather than by direct measurement of electrical power consumption.

By this method, therefore, it is possible to continuously evaluate thermal conductivity as a function of temperature in a single experiment (Ward and Skaar, 1963). In Clarke's experimental apparatus, the thermal capacity of the sink was in the order of 100 times greater than that of the test sample.

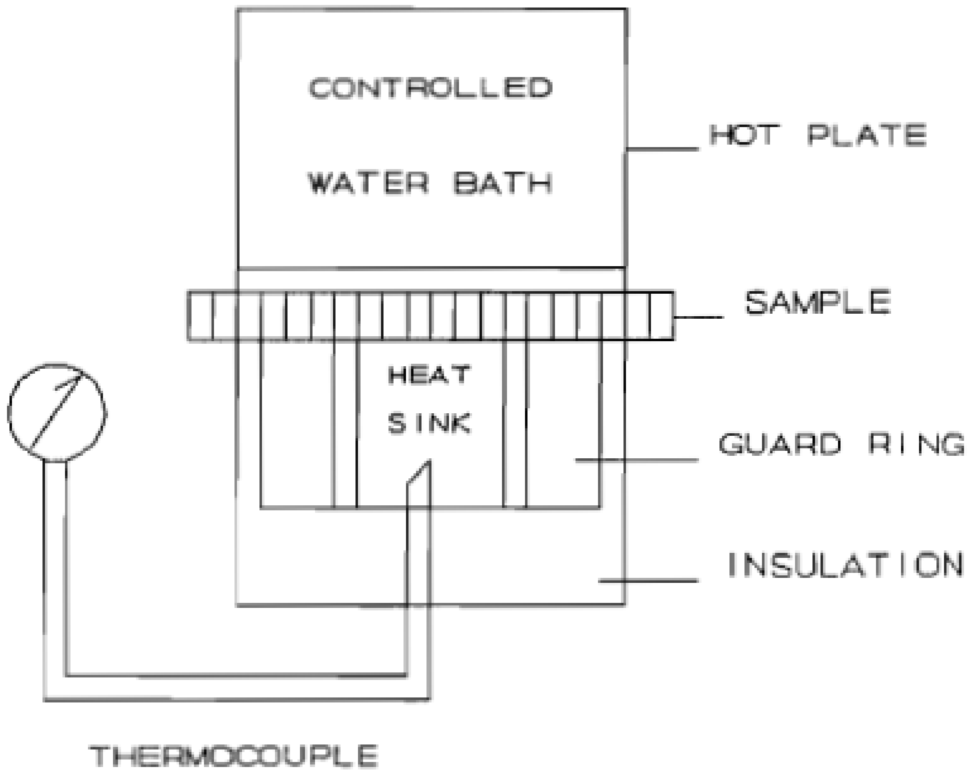

Figure 2.3: Experimental arrangement of unsteady-state method

Source: Clarke, 1954

Thus, even large errors in the assumed value of specific heat for the sample caused only negligible error in the determination of the conductivity, k. Robert and Skaar (1963) described one experimental apparatus which was a modification of Clarke's (1954) method as illustrated in Figure 2.4.

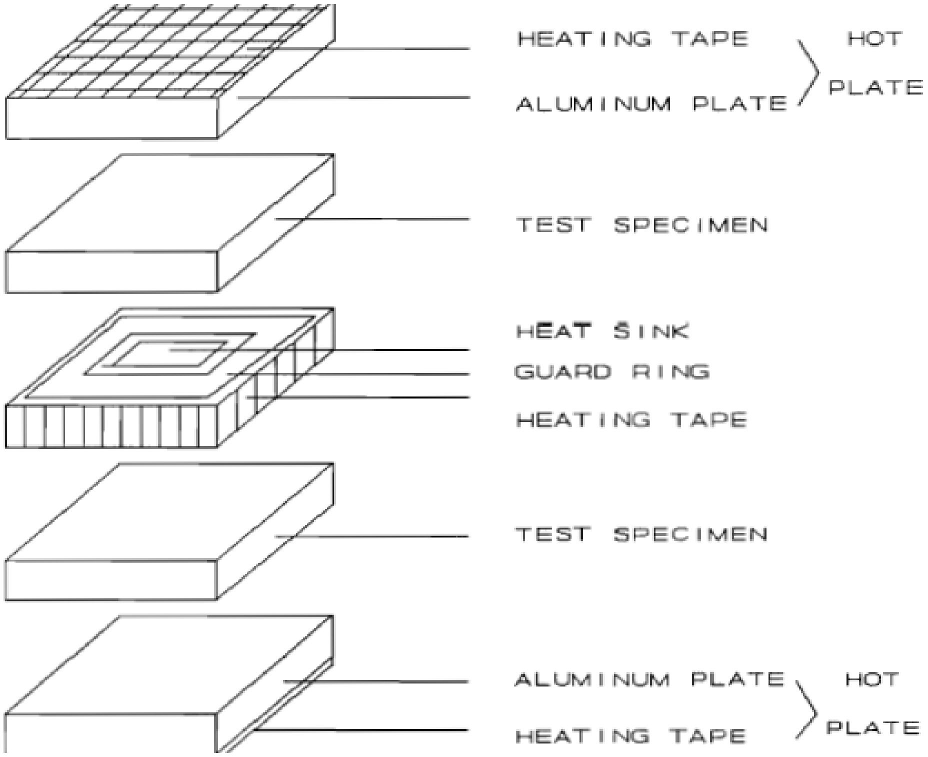

Figure 2.4: Experimental arrangement used by Robert and Skaar

Source: Robert and Skaar, 1963

Two hot plates and samples were used instead of the single units. This dual-sample arrangement doubled the heat capacity of the test sample per unit of thickness and also doubled the area effective for heat conduction. The specific heat and the thermal conductivity of particleboard with mean density 700 kg/m3 and mean moisture content 8.3% were found to increase linearly with temperature. These agree with the results obtained by others on similar types of material. The experiments completed by Robert and Skaar further demonstrated that unsteady-state methods are useful providing short test times and therefore enabling hygroscopic material to be measured.

c) Nanassy's Method

Nanassy (1978) published a transient method to determine the thermal conductivity and thermal diffusivity of waferboard. Figure 2.5 shows the apparatus. A ring-heater embedded in the center of a specimen of suitable size was electrically heated. Five slabs were held tightly between two metal plates. The temperature of the specimen at the center of the ring-heater was measured with a thermocouple. The temperature and the moisture content of the specimen were controlled by placing it in a sealed sample holder.

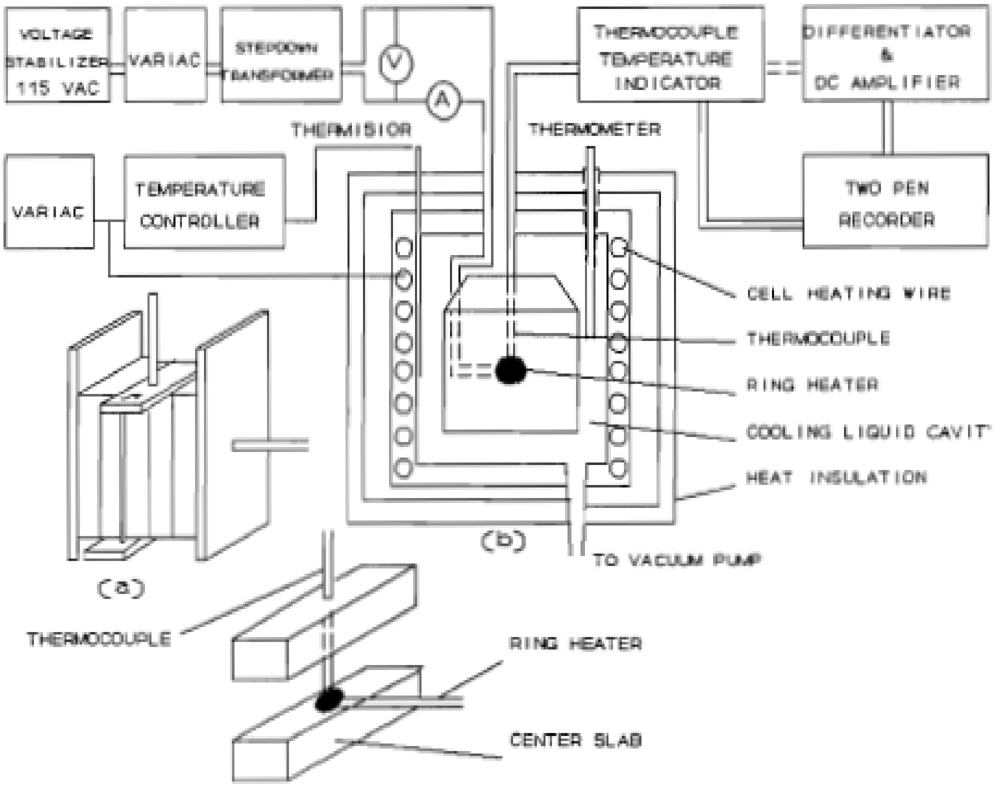

Figure 2.5: (a) Slabs between two metal plates

(b) Experimental arrangement

Source: Nanassy 1978

The calculation of thermal diffusivity and thermal conductivity was based on the equation of heat diffusion for a point heat source given by Carslaw and Jaeger (1959).

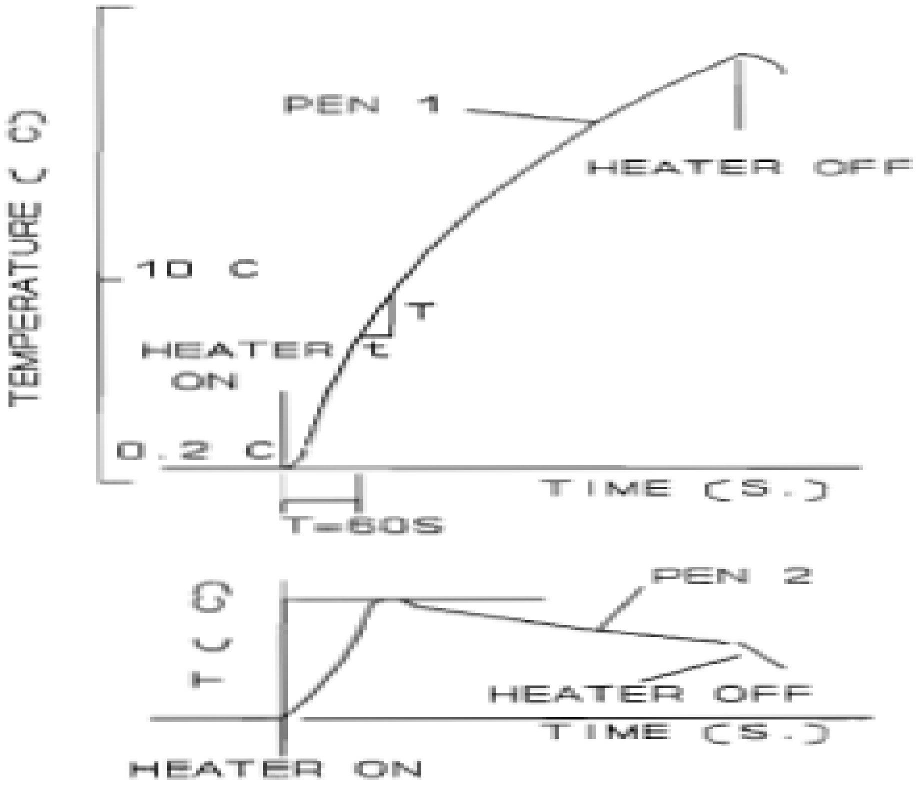

Figure 2.6: Sample chart from waferboard test

Source: Nanassy, 1978

2.5 THERMAL PROPERTIES OF WOOD-BASED COMPOSITES

2.5.1 Thermal Conductivity

Thermal conductivity of the wood has been recognized to vary with:

i. Density
ii. Moisture content
iii. Temperature
iv. Direction of heat flow with respect to grain
v. Heart wood or sap wood
vi. Type and quantity of extractive
vii. The presence of defects (Ward, 1960)

2.5.1.1 Density and Moisture Effects

The thermal conductivity of wood has been found to be linearly correlated with density (Rowley, 1933; MacLean, 1941; Narayanamurti and Ranganathan, 1941; Thunell and Lundquist, 1945; Kollmann, 1951). MacLean (1941) derived an equation for oven-dry wood based on English units, which was:

$$K = 1.39\ G + 0.165 \tag{2.8}$$

This relationship appears to be accurate for all species tested ranging in specific gravity from 0.11 to 0.76 (Kollmann, 1968). Wangaard (1969) maintained that density appears to be the only variable which significantly affects thermal conductivity. MacLean (1941) modified equation (2.21) to account for the effect of wood moisture at an average temperature of 25°C.

$$\text{For mc} < 40\ \%,\ K = G\ (1.39 + 0.028\ m) + 0.165\ 2.22 \tag{2.9}$$

$$\text{For mc} > 40\ \%,\ K = G\ (1.39 + 0.038\ m) + 0.165 \tag{2.10}$$

where G = density based on oven dry weight and volume at moisture content m

m = moisture content (oven-dry base)

K = conductivity in Btu.in./hr. ft2.°F

Rowley (1933) found thermal conductivity increased linearly with moisture content. However, Kollmann (1951, 1956) found there was no linear relationship existing above 0.8 g/cm3. Kollmann (1968) published a group of data in Figure 2.7, which showed that at the same density, thermal conductivity increases in proportional to the moisture content. Maku (1954) used a quadratic formula for the density range from 0.3 to 1.56 g/cm3.

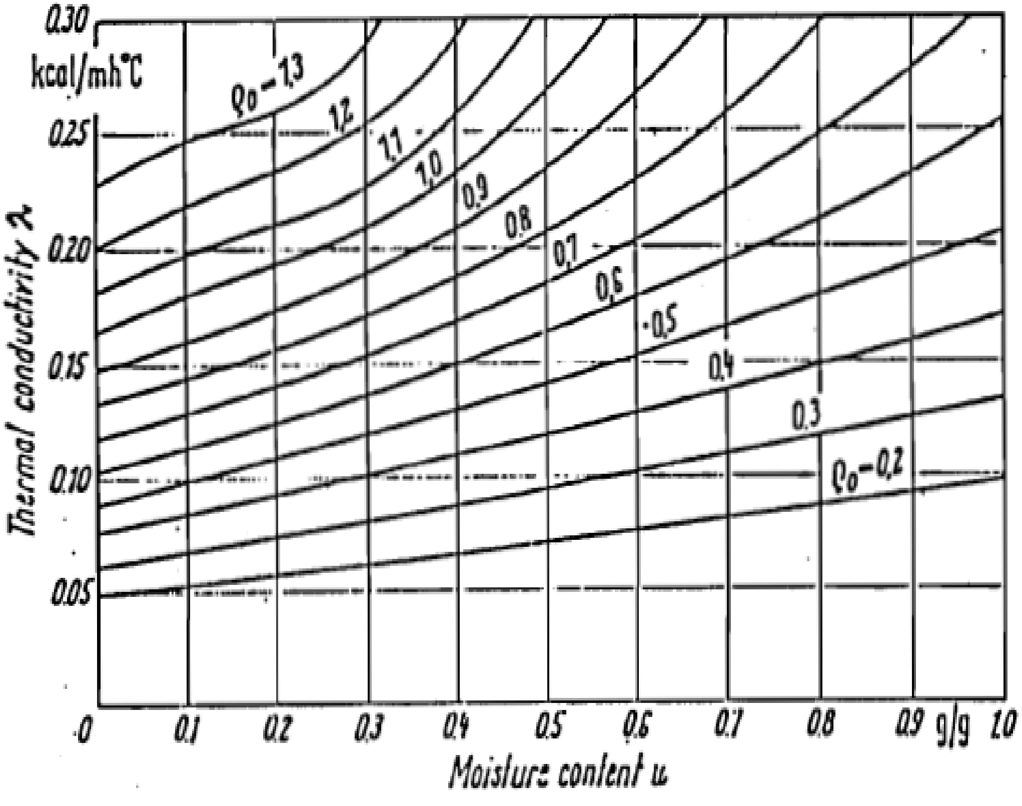

Figure 2.7: Thermal conductivity on moisture content

Source: Kollman, 1968

2.5.1.2 Temperature Effects

Gammon (1987) provided a group of data as illustrated in Figure 2.8 for oven-dry wood based on the work of MacLean (1941), Maku (1954), Brown (1973) and Knudson (1979).

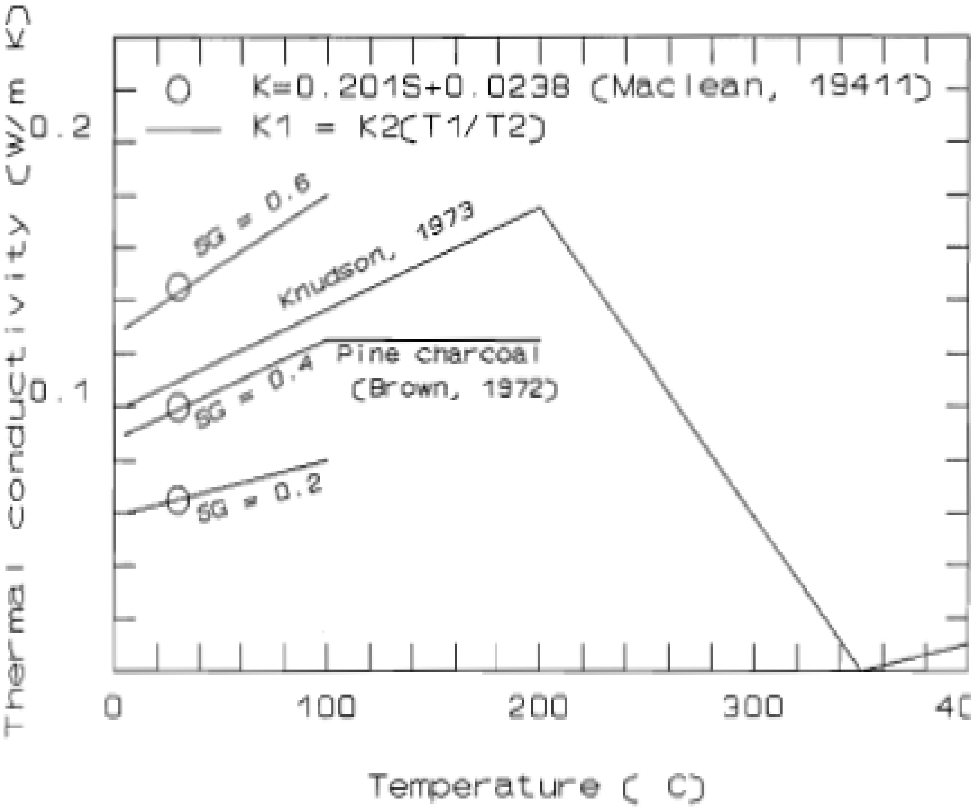

Figure 2.8: Thermal conductivity of oven-dry wood

Source: Gammon, 1987

2.5.1.3 Grain Direction Effects

The thermal conductivity of wood in the radial direction has been found to be about 5 to 10 % greater than in the tangential direction (Griffiths and Kaye, 1923; Wangaard, 1940). Conductivity in the longitudinal direction has been found to be about 2.25 to 2.75 times the conductivity across the grain (Kollmann, 1968) when moisture content was 6 to 10%. Kollmann and Malmquist (1956) developed a model to describe the effect of fiber orientation on thermal conductivity. Wood and wood-based composite materials were defined as composing of layers of fiber material and air.

The minimum and maximum thermal conductivity could be calculated from layer thicknesses and the conductivity of air and wood cell wall substance. For a body with a mixed arrangement of layers, a weighted average conductivity was obtained by means of the "bridge factor" concept. Therefore, the thermal conductivity of solid wood, particleboard and fiberboard was separated by simply varying the "bridge factor".

2.5.1.4 Composite Materials

Kollmann and Malmquist (1956) summarized thermal conductivity data from many sources. This showed the dependence of the thermal conductivity of wood, particleboard and fiberboard upon specific gravity. Solid wood had the highest conductivity value, and fiber board the lowest, with plywood being intermediate as illustrated in Figure 2.9. Lewis (1967) tested fiber board and particle board and obtained the same results.

The thermal conductivity of particleboard varied with temperature (Gilbo, 1951; Kollmann, 1951; Kollmann, 1952; Lewis, 1967; Ward and Skaar 1963). The same is true for wafer board (Nanassy, 1978). There is general agreement that there is a small positive linear effect of temperature on the conductivity value (Humphrey, 1989). The thermal conductivity of wood-based composites is also affected by moisture content.

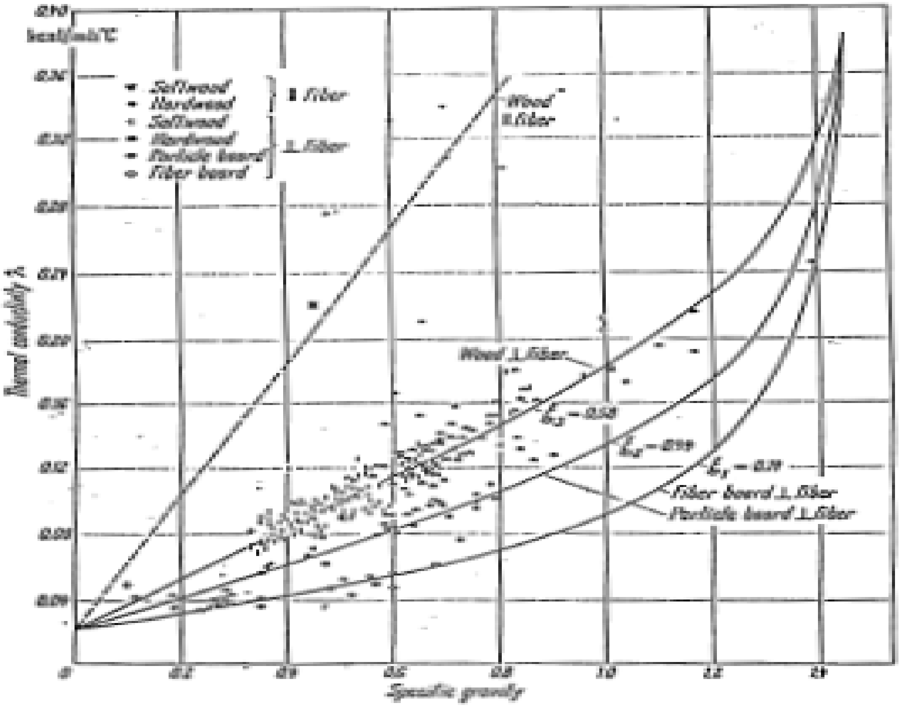

Figure 2.9: Dependence of the thermal conductivity of wood, particleboard and fiberboard upon specific gravity

Source: Kollman, 1956

Since it is difficult to prevent moisture movement in the current test methods, few experimental results have been published. Nanassy (1978) reported that, as would be expected, the thermal conductivity of waferboard increases with an increase in moisture content.

2.5.2. Specific Heat

There is quite a lot information on the specific heat of wood. In graphical form (Figure 2.10), Gammon (1987) summarized the equations for specific heat of oven dry wood and wood-based materials as a function of temperature ranging from -30°C to 140°C. All the equations have showed a linear relationship between specific heat and temperature.

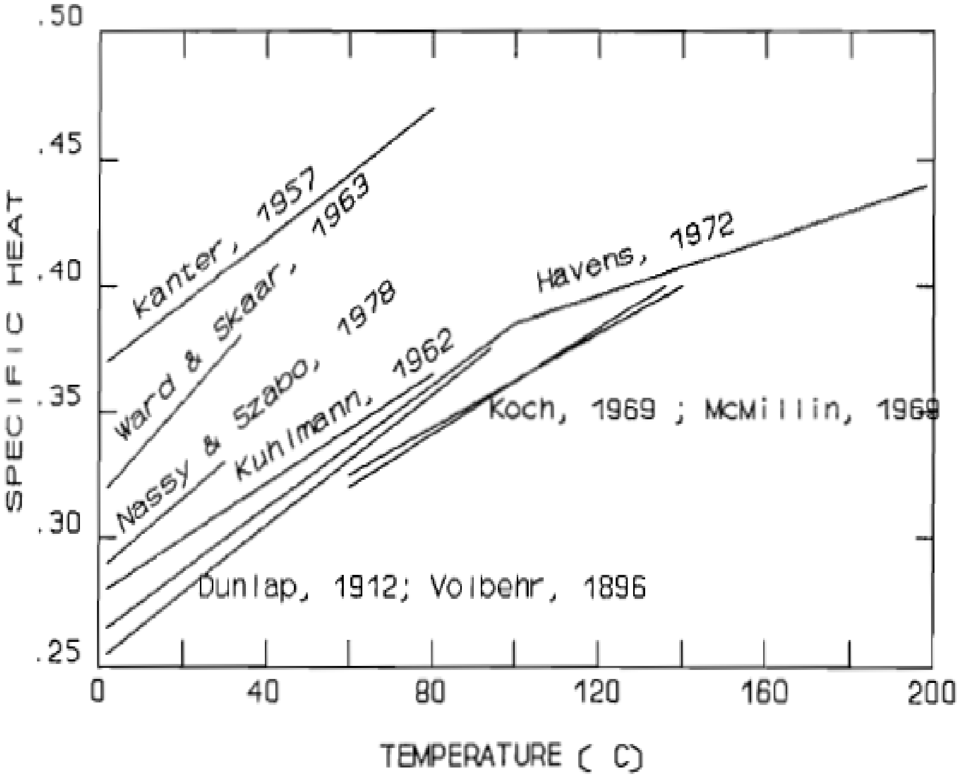

Figure 2.10: Oven-dry specific heat of wood and wood composite materials

Source: Gammon, 1987

The specific heat was assumed to be independent of species (Dunlap 1912; Kanter, 1957). However, large differences may be present in species with abnormal chemical composition (McMillin, 1969).

2.5.3 Thermal Diffusivity

There are few reports based on direct measurement methods for thermal diffusivity of wood and wood based materials, available data are calculated from the relation ($\alpha = K/c\rho$). Figure 2.11 showed the influence of density and moisture content on diffusivity (Kollmann, 1968). Wangaard (1969) calculated the diffusivity of southern pine. The reversal of trends showed that diffusivity decreased slightly with increasing density and moisture content (at the same density). Nanassy (1978) measured the diffusivity of waferboard, and found that it increased with temperature and at any particular temperature; it decreased with an increase in moisture content.

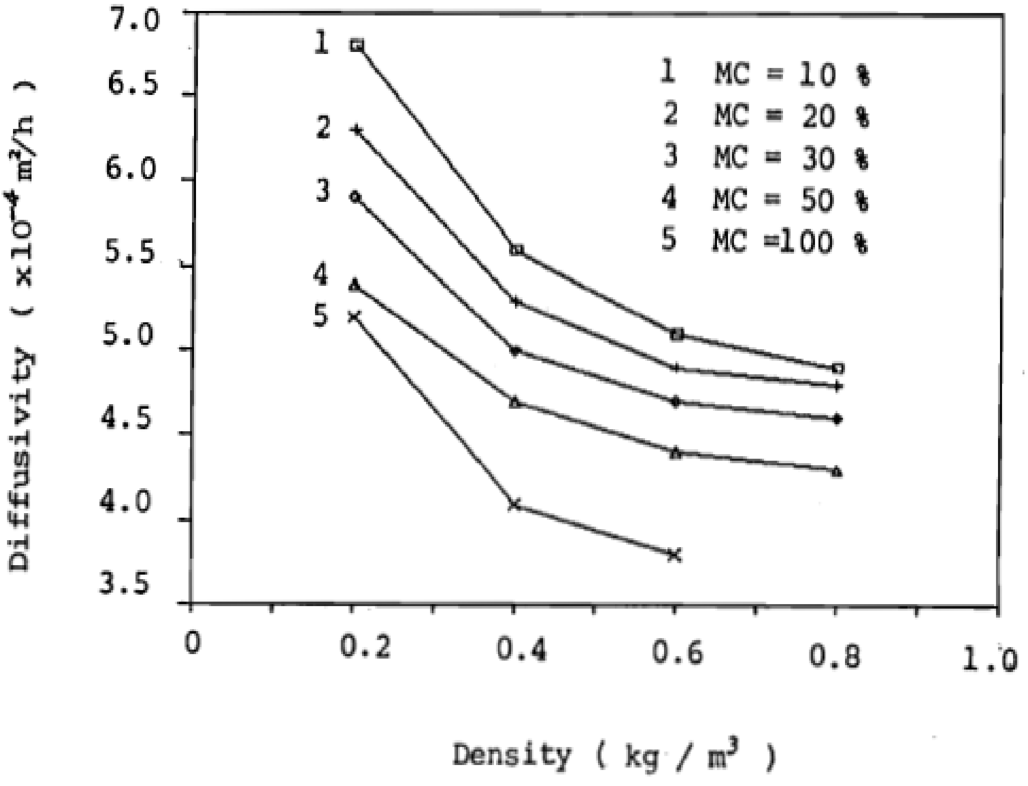

Figure 2.11: Diffusivity perpendicular to the grain as influenced by density and moisture content

Source: Kollman, 1968

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will provide the detail explanations on the methodology that carries out for this project entitled “Computational Analysis of Heat Conduction in Nanowood Composite Boards” from the beginning until the end. Methodology can properly refer to the theoretical analysis of the methods appropriate to a field of study or to the body of methods and principles particular to a branch of knowledge. The methodology acts as the guidance or step that needs to be follows and this will ensure the project done according to the planning. The flow chart in Figure 3.1 shows the overall flow of project in step by step process.

3.2 FLOW CHART

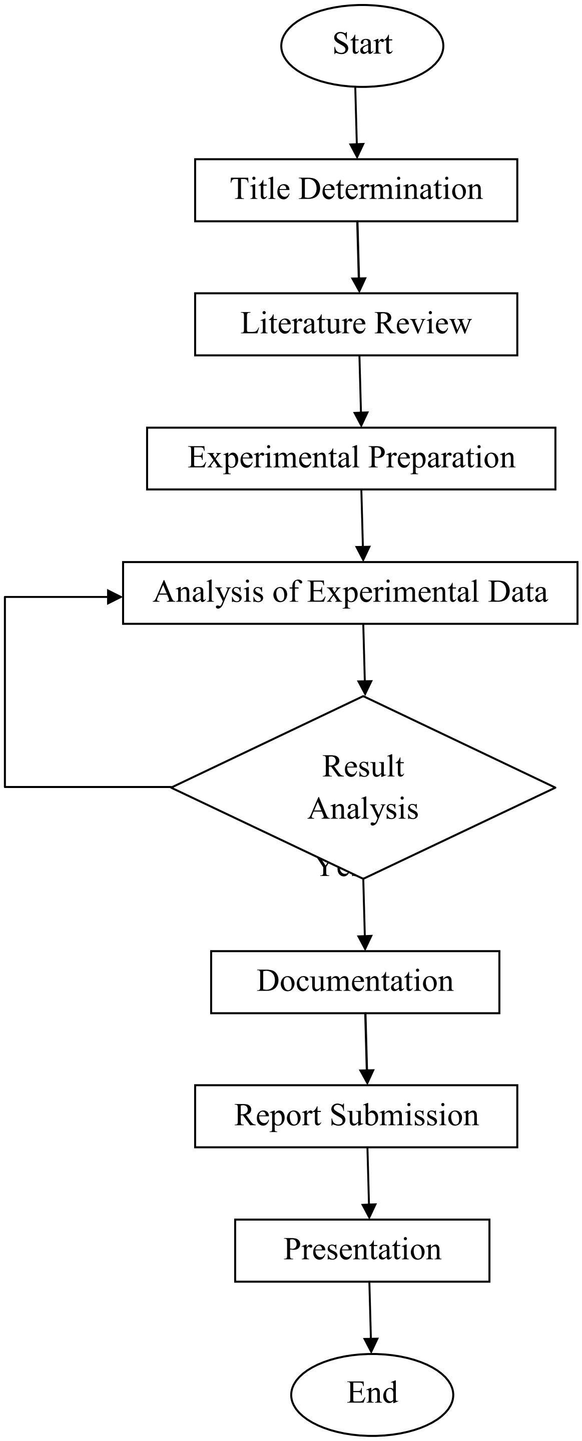

Figure 3.1: FYP flow chart

3.3 FLOW CHART DESCRIPTIONS

3.3.1 Title Determination

Title determination is one of the most important aspects in final year project. It is essential to pick a title which you are only interested into. This is because you are going to spend much time working on the project such as doing the experiments in the laboratory. You need to identify what are the title options available before making a short list to choose the best title. Once confirmed, submit the title form.

3.3.2 Literature Review

Literature review is a survey and discussion of the literature in a given area of study. It is a concise overview of what has been studied, argued, and established about a topic, and it is usually organized chronologically or thematically. A literature review is written in essay format. It is not an annotated bibliography, because it groups related works together and discusses trends and developments rather than focusing on one item at a time. It is not a summary; rather, it evaluates previous and current research in regard to how relevant and/or useful it is and how it relates to your own research. It is written to highlight specific arguments and ideas in a field of study. By highlighting these arguments, the writer attempts to show what has been studied in the field, and also where the weaknesses, gaps, or areas needing further study are. The studies may come from journal from Ez-Proxy link of University of Malaysia Pahang, books and internet sources.

3.3.3 Experimental Preparation

3.3.3.1 Medium Density Fiber (MDF) Board Preparation

There are a few processes being implemented in producing Medium Density Fiber (MDF) boards. Wood fiber, nanoparticles and Urea-Formaldehyde (UF) resin need to be mixing together before the mat of the wood is forming.

Figure 3.2: Wood fiber, nanoparticles and UF resin are mixing together

The materials are then ready to go through mat forming process through hot and cold pressing.

Figure 3.3: Mat forming and cold pressing processes

After cold pressing process, thermocouple is put inside the core to measure the temperature profile during hot pressing process.

Figure 3.4: Hot pressing process

MDF boards are completed.

Figure 3.5: Ready MDF board

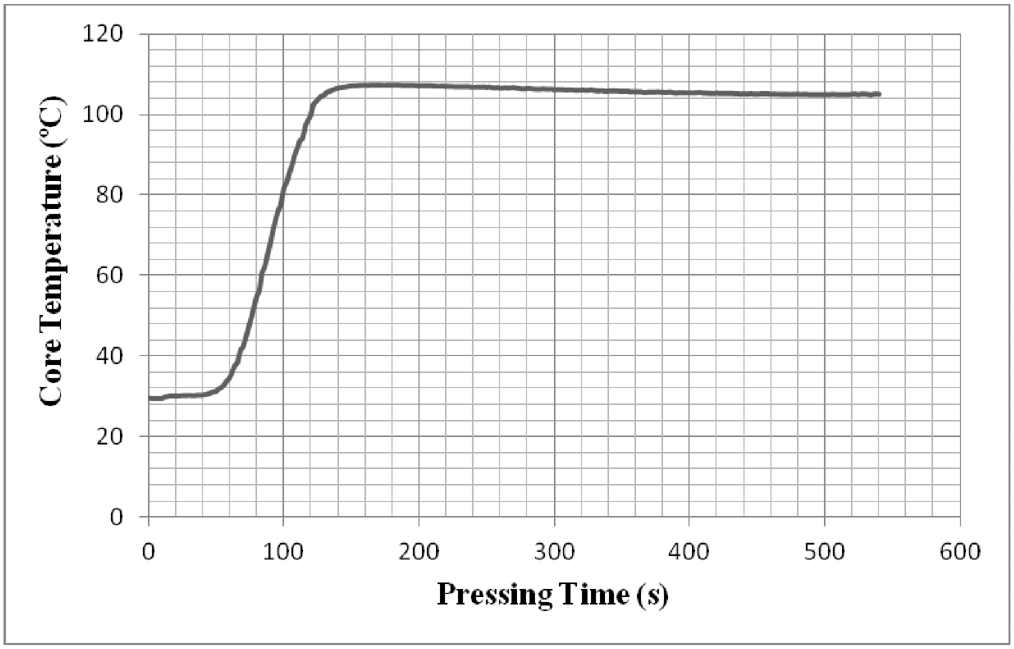

Figure 3.6: Temperature profile of control/standard board

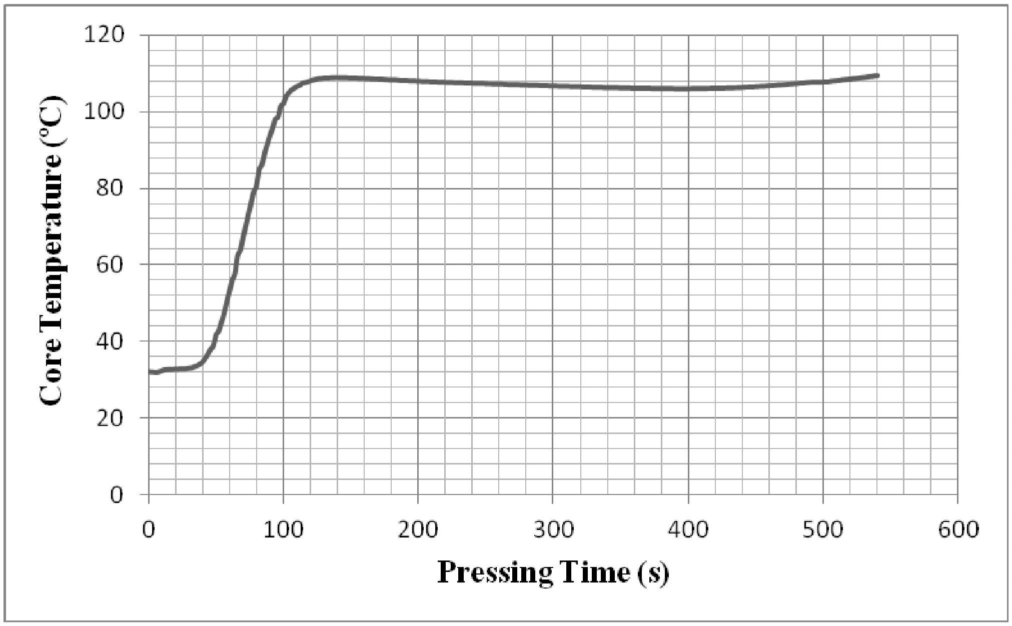

Figure 3.7: Temperature profile of copper board

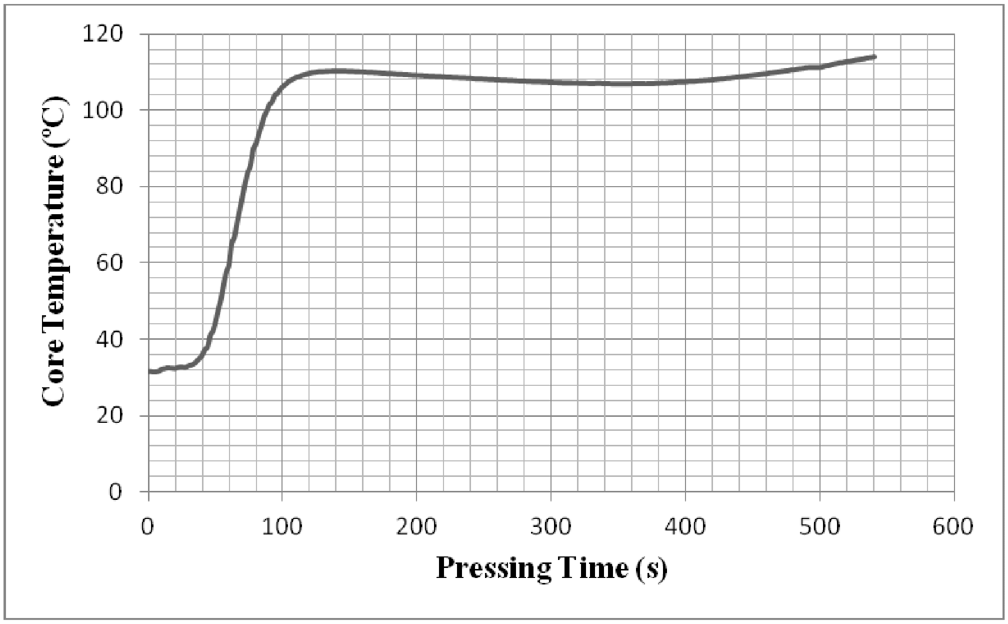

Figure 3.8: Temperature profile of carbon nanotube board

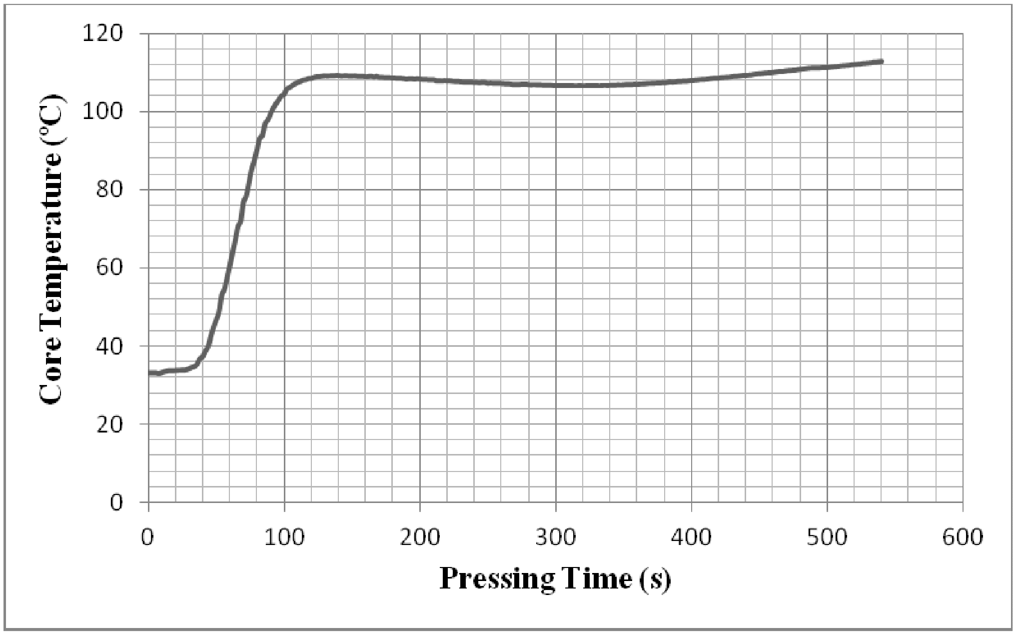

Figure 3.9: Temperature profile of prepared carbon board

3.3.3.2 Thermal Properties Measurement

KD2 Pro Overview

The KD2 Pro uses 3 thermal properties sensors to measure thermal diffusivity, specific heat, thermal conductivity and thermal resistivity. The KD2 Pro allows the user to choose an automated mode where the reading is displayed directly or a manual mode where they can download the raw values from each reading for further analysis using a spreadsheet program as required by IEEE and ASTM standards. Its applications:

- Soil heat flux in energy balance studies.
- Heat dissipation from buried power lines.
- Geothermal designs.
- Soil heat flow under fires.
- Thermal properties in relation to moisture and density.

Figure 3.10: KD2 Pro apparatus

The sensor which is suitable to use in this thermal properties experiment is SH-1. The specifications of the sensor are as follows:

30 mm dual-needle (SH-1):
Size: 1.3 mm diameter x 30 mm long, 6 mm spacing
Range: 0.02 to 2.00 W /m°K (conductivity)
 0.5 to 50 m°K/W (resistivity)
 0.1 to 1 mm^2/s (diffusivity)
 0.5 to 4 MJ/m-^{3}°K^{-1} (volumetric specific heat)

- **Thermal Conductivity**

The thermal conductivity of the solids is found to be varies linearly with the temperature. When the temperature is increase, the thermal conductivity of the solids is also increase. The values are automatically appearing on the screen. The experimental values then are compared with theoretical values obtain from software. Thermal conductivity equation is presented as follows by Frank (1958):

$$q = - KA \, (dT/dx) \tag{3.1}$$

- **Thermal Diffusivity**

The relationship between temperature and thermal diffusivity is they are varies linearly. Thermal diffusivity of wood based composites also can be obtaining from the thermal conductivity apparatus, KD2 Pro. It is automatically preview the readings of thermal diffusivity as well as thermal conductivity values of the wood. In heat transfer, David R. (2009) has proposed an equation of thermal diffusivity which is:

$$\alpha = k/c_p.\rho \tag{3.2}$$

- **Specific Heat and Specific Volume**

As we know, the specific heat value of solids is equal to its specific volume. But, there is no specific relation between thermal conductivity and specific heat. In heat transfer, the specific heat of most materials is temperature dependent. During the experiment, KD2 Pro apparatus is also automatically previewed the values of specific heat capacity of the five wood based composite specimens. In heat transfer analysis generally, specific heat capacity can be found using equation:

$$c = Q/m.(T2-T1) \tag{3.3}$$

Figure 3.11: Thermal properties measurement

3.3.3.3 Mechanical Testing

Brinell Hardness Test

The test is achieved by applying a known load to the surface of the tested material through a hardened steel ball of known diameter. The diameter of the resulting permanent impression in the tested metal is measured and the Brinell Hardness Number is calculated as:

$$BHN = 2\ F / (\pi\ D\ (D - (D^2 - d^2)^{½})) \tag{3.4}$$

where: BHN = Brinell Hardness Number

P = load on the indenting tool (kg)

D = diameter of steel ball (mm)

d = measure diameter at the rim of the impression (mm)

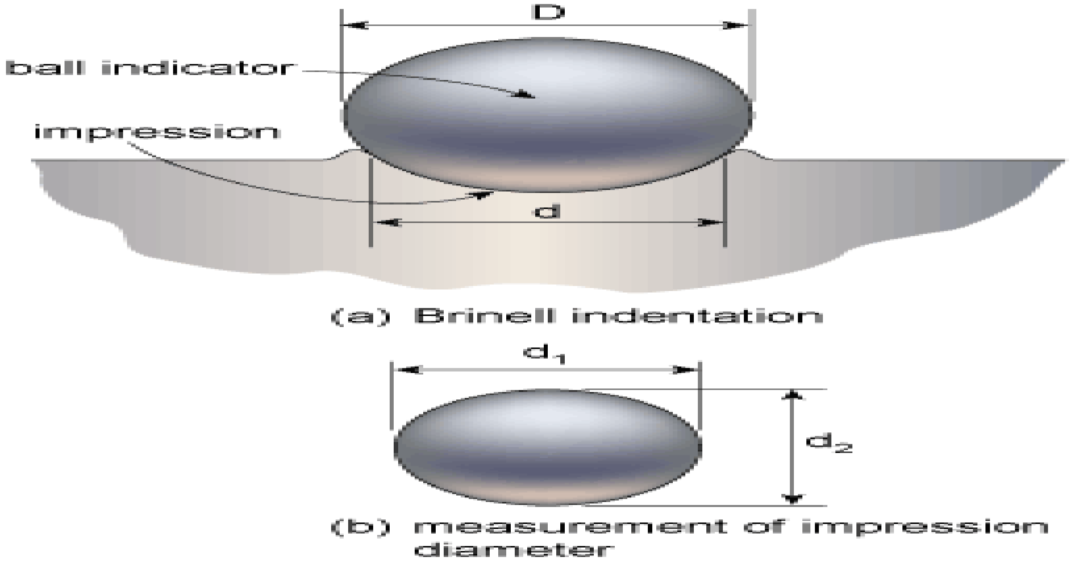

Figure 3.12: Brinell Hardness Test

3.3.4 Data Collection and Analysis of Experimental Data

From the very first of Final Year Project 1, students had given a task from the supervisor to search and collect any sources, journals and articles that have been conducted by past researchers that relate to the project title. The sources may have come from the internet. After conducted some experiments for the project, the experimental result then needs to be collected for further analysis. The experimental result is then being compared with the theoretical result. After analyzing the result, it needs to be compared and relate to the sources and researches made by the past researchers.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter is mainly briefing and discussing about the result of thermal properties measurement which are being obtained from experiments that have been implemented. On the other hand, the result of mechanical testing on the Medium Density Fiber (MDF) boards is also included. Nanoparticle concentration that has been used in this project is 1% on each board.

4.2 THERMAL PROPERTIES

The thermal properties of Medium Density Fiber (MDF) board were measured using thermal properties measuring apparatus, KD2 Pro. From the apparatus, thermal conductivity, thermal diffusivity, thermal resistivity and specific heat can be obtained for further analysis.

4.2.1 Thermal Conductivity

Thermal conductivity of five samples of boards is obtained from an experiment using KD2 Pro device. The result is shown in Table 4.1. In the past observations, thermal conductivity was found to be a function of the temperature (ranging between 10ºC and

30ºC). Thermal conductivity increases with rising temperature, moisture content and density. Table 4.1 shows that thermal conductivity rate increasing with the increasing of temperature. The thermal conductivity varies linearly with temperature.

Table 4.1: Thermal conductivity of MDF boards

Types	Temperature (ºC)	Thermal Conductivity (W/m.K)
Carbon Nanotube (CNT)	28.78	0.144
	27.35	0.141
	26.69	0.138
Control/Standard Board (CB)	27.31	0.124
	26.51	0.119
	26.17	0.118
Prepared Carbon (PC)	29.80	0.144
	26.06	0.133
	24.93	0.132
Copper (CU)	25.16	0.130
	24.90	0.153
	24.70	0.153
Activated Carbon (AC)	24.64	0.137
	24.73	0.134
	24.91	0.134

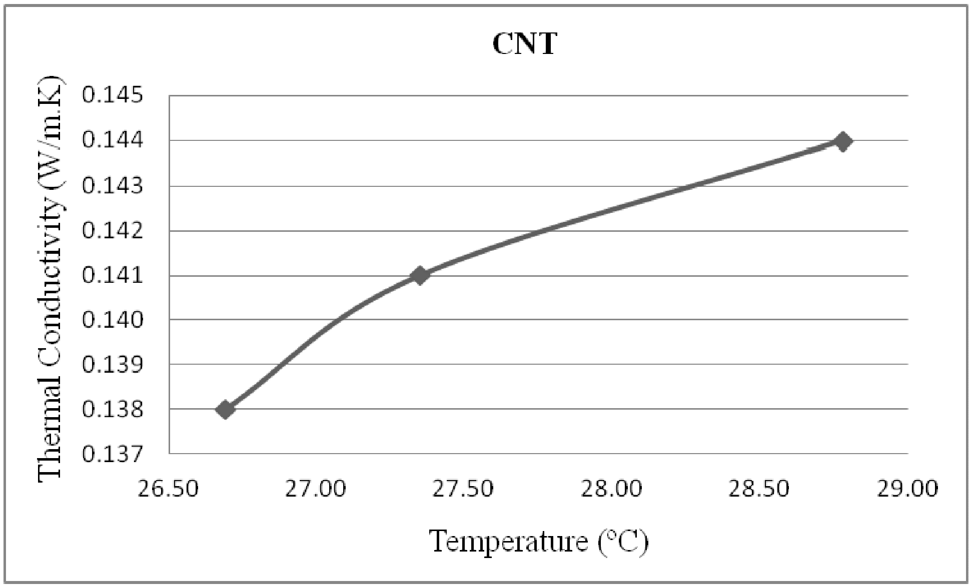

Figure 4.1 (a): Thermal conductivity of CNT board

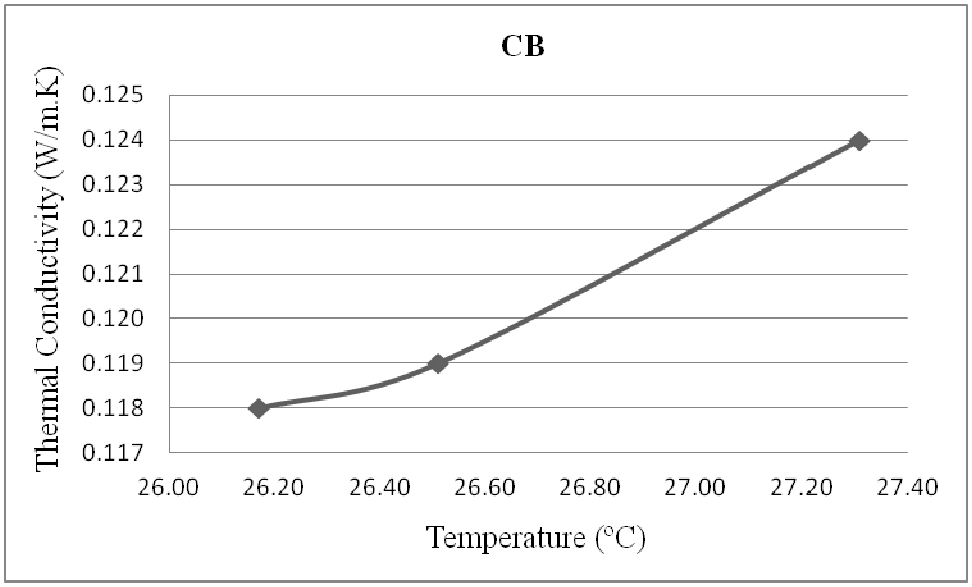

Figure 4.1 (b): Thermal conductivity of CB

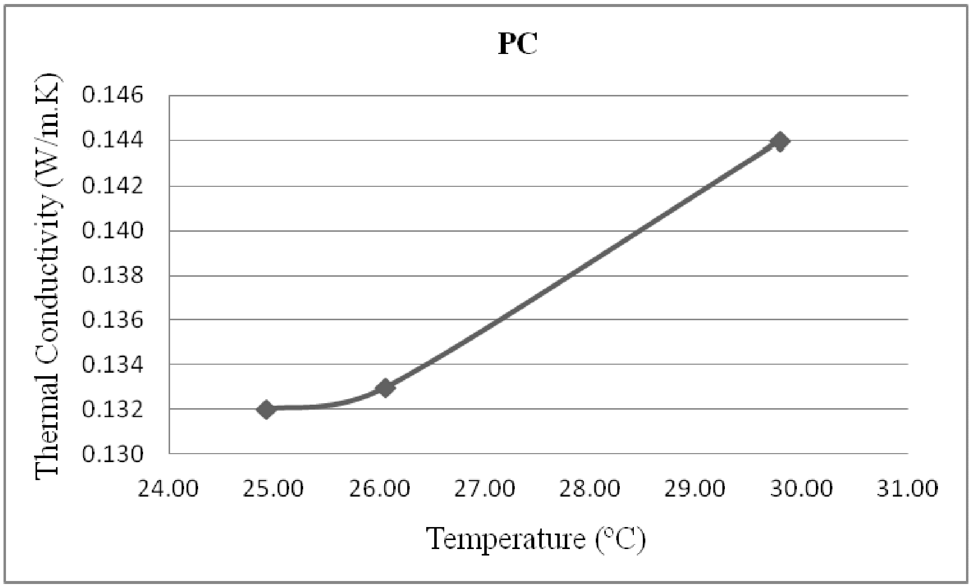

Figure 4.1 (c): Thermal conductivity of PC board

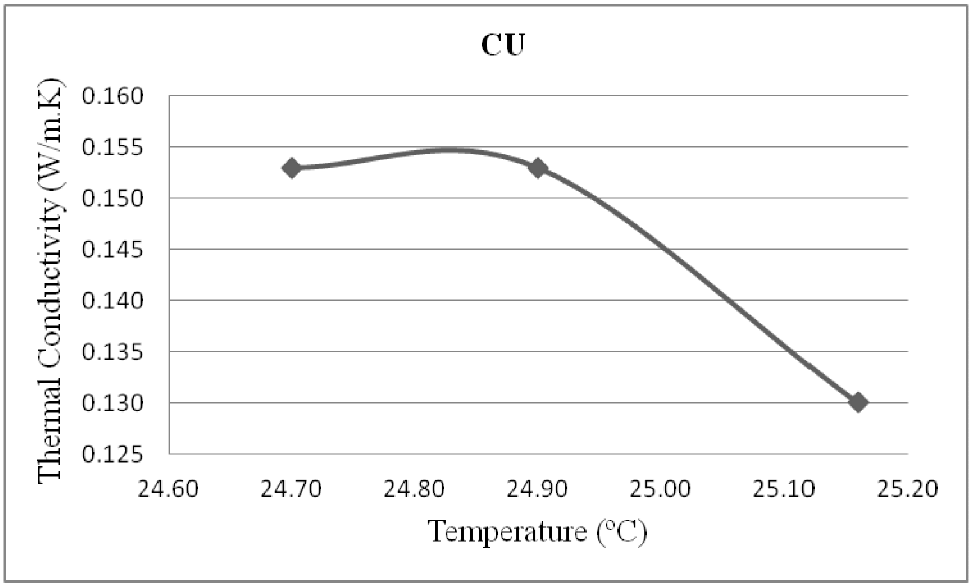

Figure 4.1 (d): Thermal conductivity of CU board

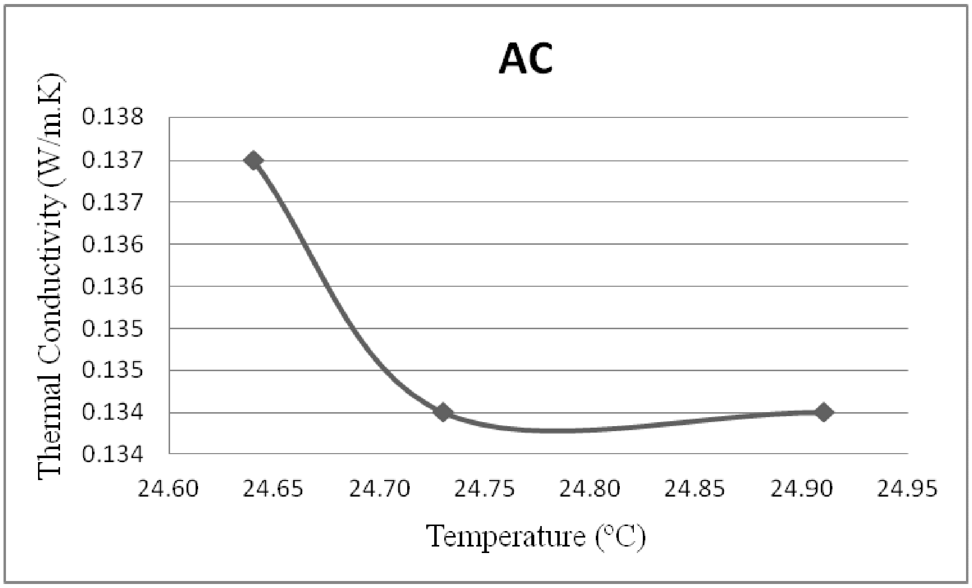

Figure 4.1 (e): Thermal conductivity of AC board

4.2.1.1 Comparison of Thermal Conductivity at 25ºC

All of the five samples of Medium Density Fiber (MDF) boards are then being obtained and compared with temperature at 25 ºC for thermal conductivity value. The result is shown as:

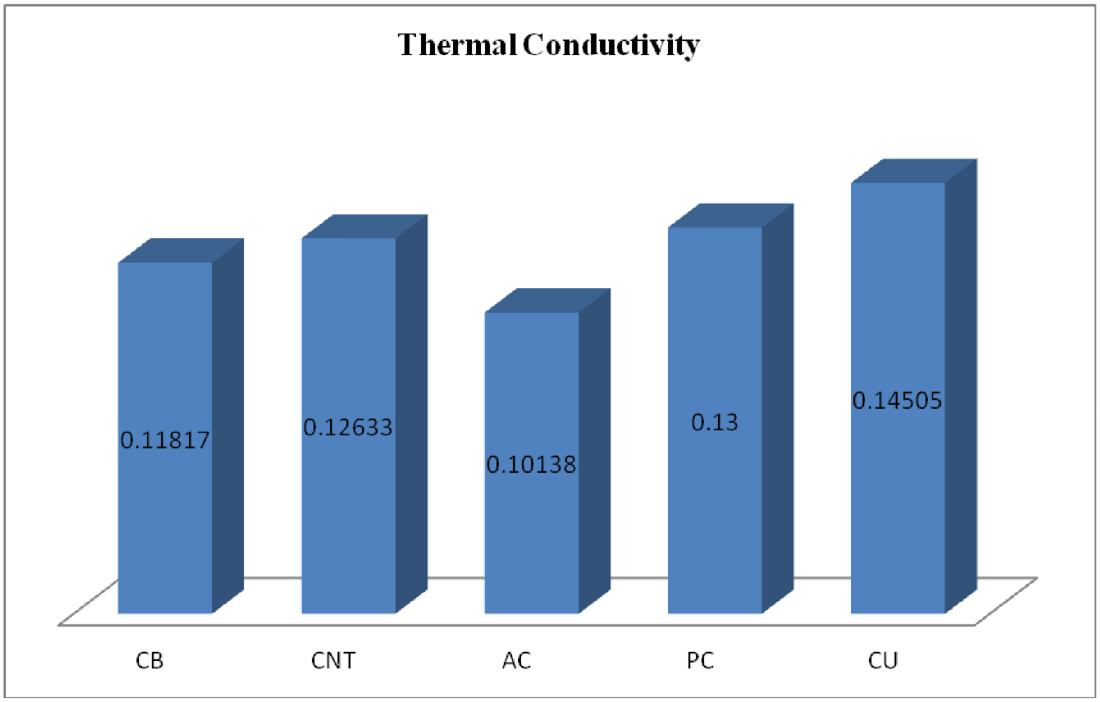

Figure 4.1 (f): Thermal conductivity of MDF boards at 25ºC

From the graph shown, it can be seen that copper board has the highest value of thermal conductivity among the five types of boards. Prepared carbon and carbon nanotube boards have thermal conductivity values which are nearly same when they are obtained at 25ºC. Activated carbon board has the lowest thermal conductivity value among all types of boards.

4.2.2 Thermal Diffusivity

According to Wangaard, (1969), thermal diffusivity, α determines the rate of temperature change in a material when it is subjected to a change in ambient temperature. The diffusion coefficient decreases with rising density and moisture content. The result below shows that thermal diffusivity varies linearly with the change of temperature.

Table 4.2: Thermal diffusivity of MDF boards

Types	**Temperature (ºC)**	**Thermal Diffusivity (mm²/s)**
Carbon Nanotube (CNT)	28.78	0.122
	27.35	0.119
	26.69	0.117
Control/Standard Board (CB)	27.31	0.144
	26.51	0.141
	26.17	0.141
Prepared Carbon (PC)	29.80	0.133
	26.06	0.128
	24.93	0.128
Copper (CU)	25.16	0.120
	24.90	0.125
	24.70	0.125
Activated Carbon (AC)	24.64	0.157
	24.73	0.152
	24.91	0.152

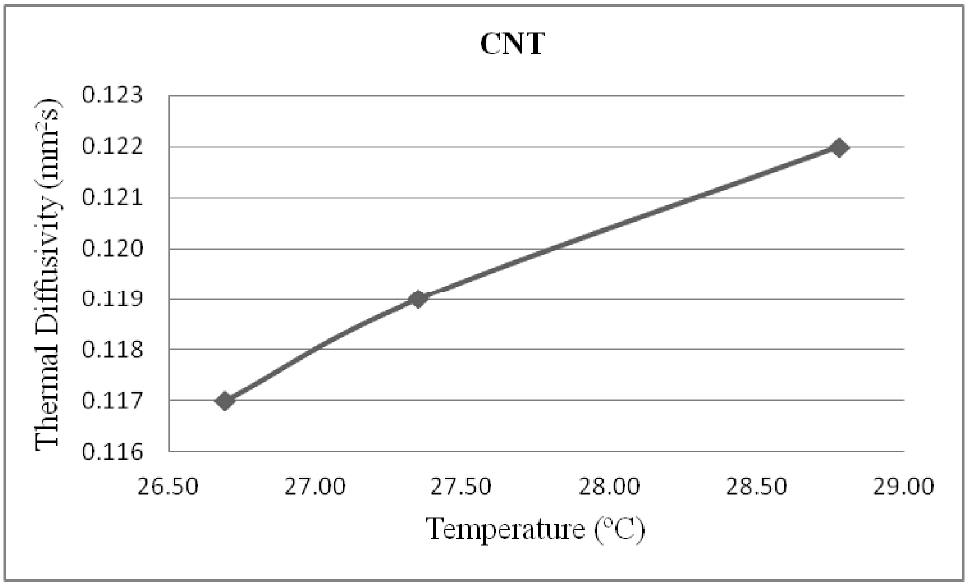

Figure 4.2 (a): Thermal diffusivity of CNT board

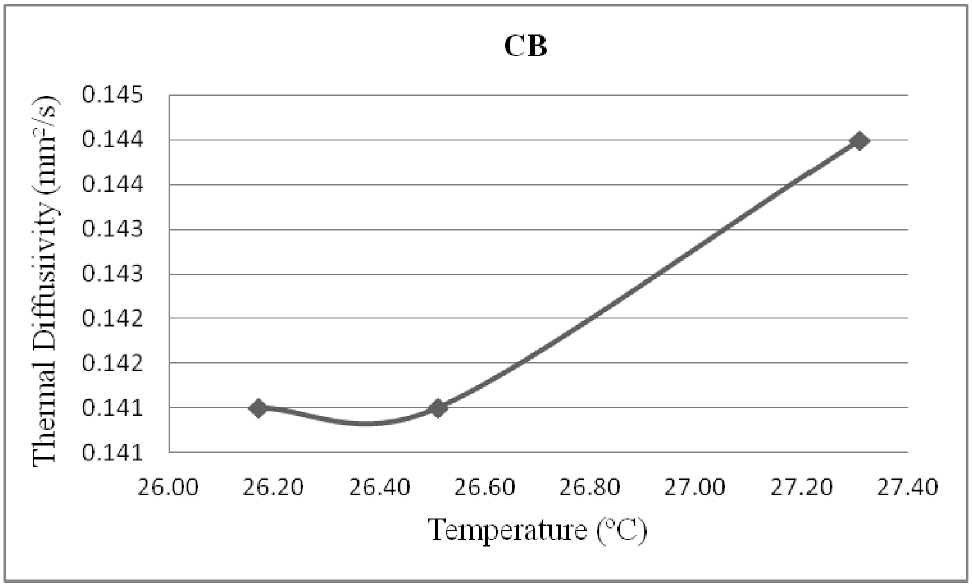

Figure 4.2 (b): Thermal diffusivity of CB

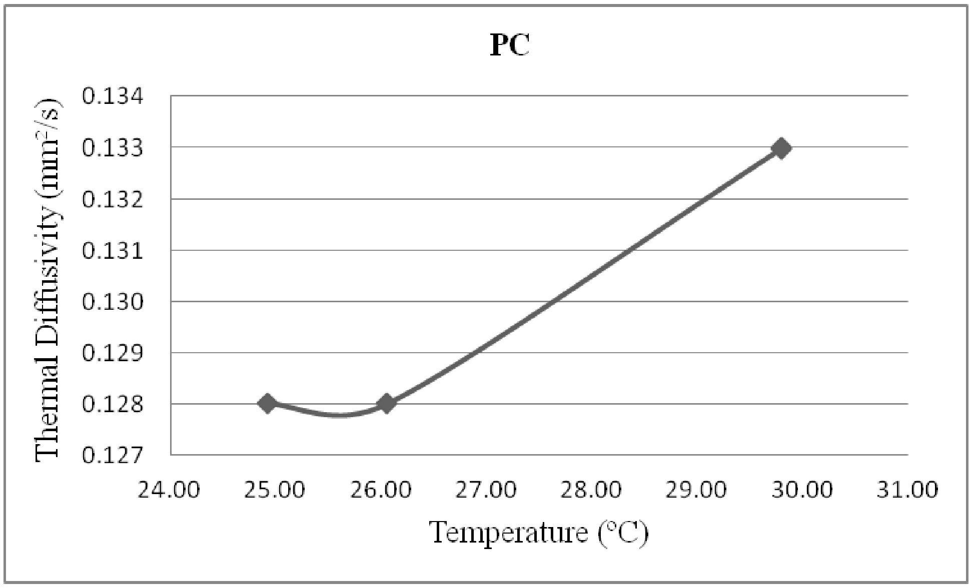

Figure 4.2 (c): Thermal diffusivity of PC board

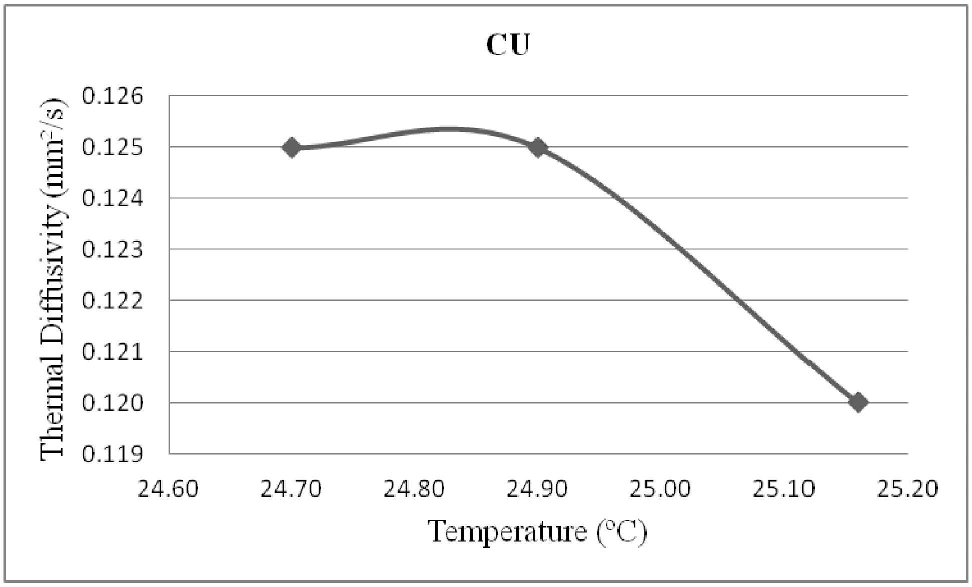

Figure 4.2 (d): Thermal diffusivity of CU board

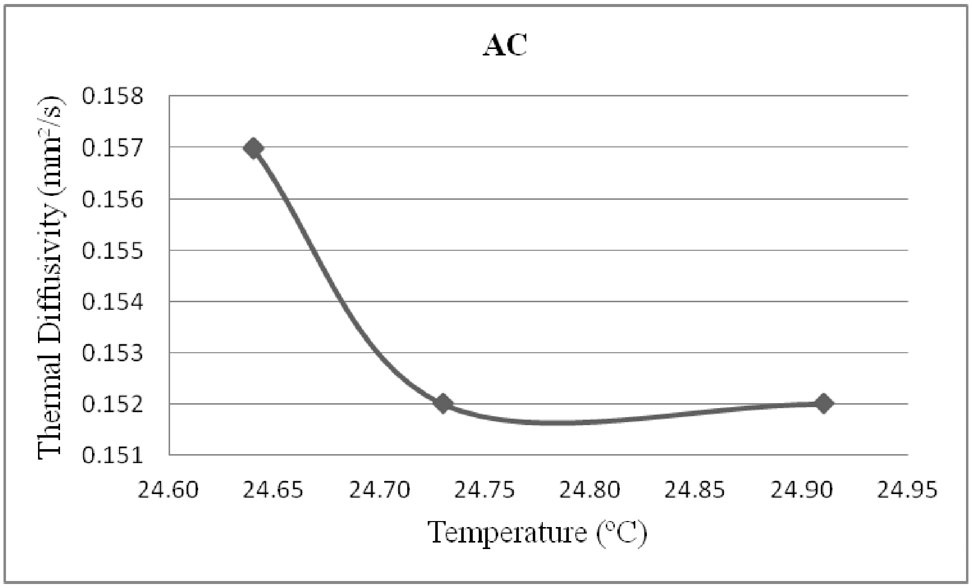

Figure 4.2 (e): Thermal diffusivity of AC board

4.2.2.1 Comparison of Thermal Diffusivity at 25ºC

All of the five samples of Medium Density Fiber (MDF) boards are then being obtained and compared with temperature at 25 ºC for thermal diffusivity value. The result is shown as:

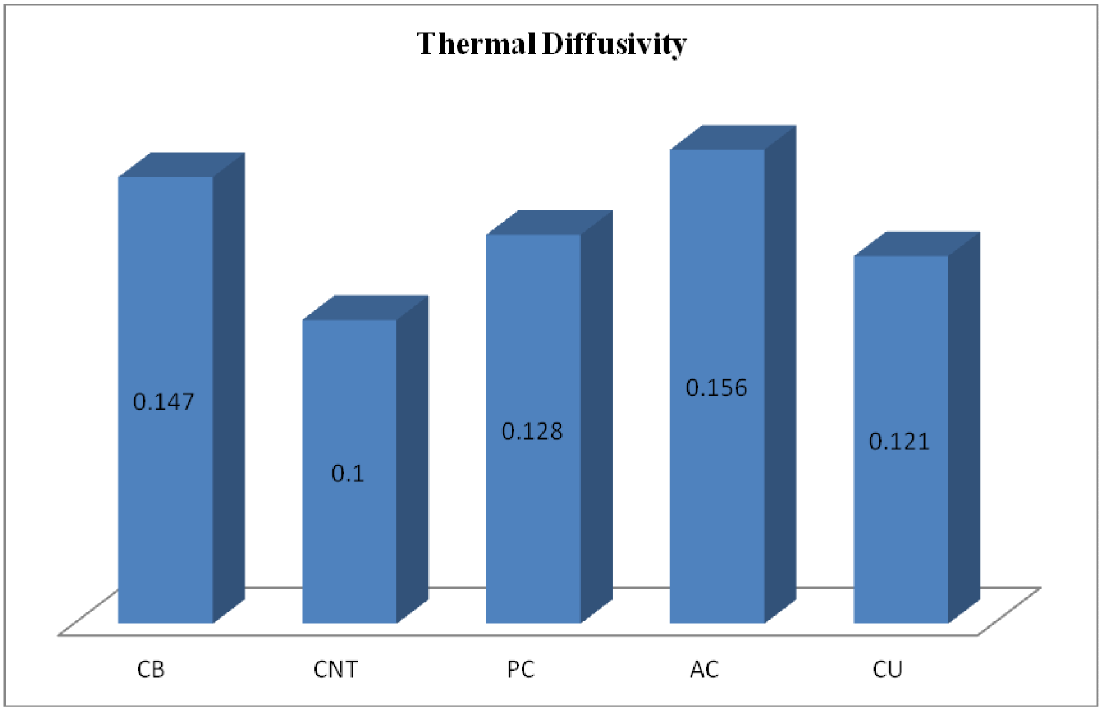

Figure 4.2 (f): Thermal diffusivity of MDF boards at 25ºC

Activated carbon board obtained the highest value of thermal diffusivity at 25ºC. It is followed by prepared carbon, copper and carbon nanotube board.

4.2.3 Thermal Resistivity

Thermal resistivity of wood-based materials is the inverse of the thermal conductivity. When the temperature is increasing, the thermal resistivity is decreasing. But, for some samples in this project, copper and activated carbon is showing that when the temperature is increasing, the thermal resistivity is also increasing as well. Table 4.3 is showed the data thermal resistivity of all samples.

Table 4.3: Thermal resistivity of MDF boards

Types	Temperature (ºC)	Thermal Resistivity (ºC.cm/W)
Carbon Nanotube (CNT)	28.78	695.1
	27.35	710.9
	26.69	723.9
Control/Standard Board (CB)	27.31	807.3
	26.51	840.8
	26.17	844.3
Prepared Carbon (PC)	29.80	694.5
	26.06	752.3
	24.93	758.7
Copper (CU)	25.16	772.0
	24.90	651.9
	24.70	654.4
Activated Carbon (AC)	24.64	727.7
	24.73	744.5
	24.91	746.7

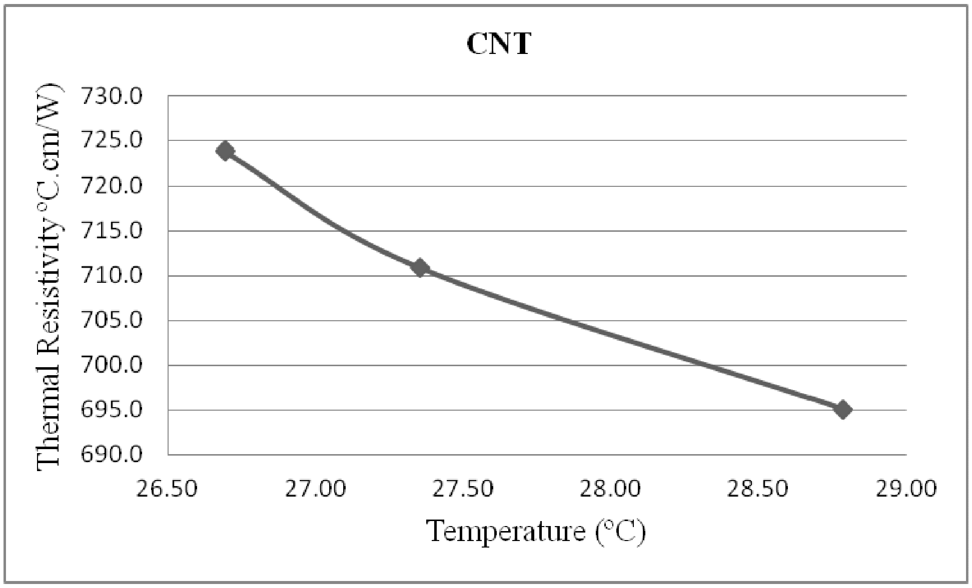

Figure 4.3 (a): Thermal resistivity of CNT board

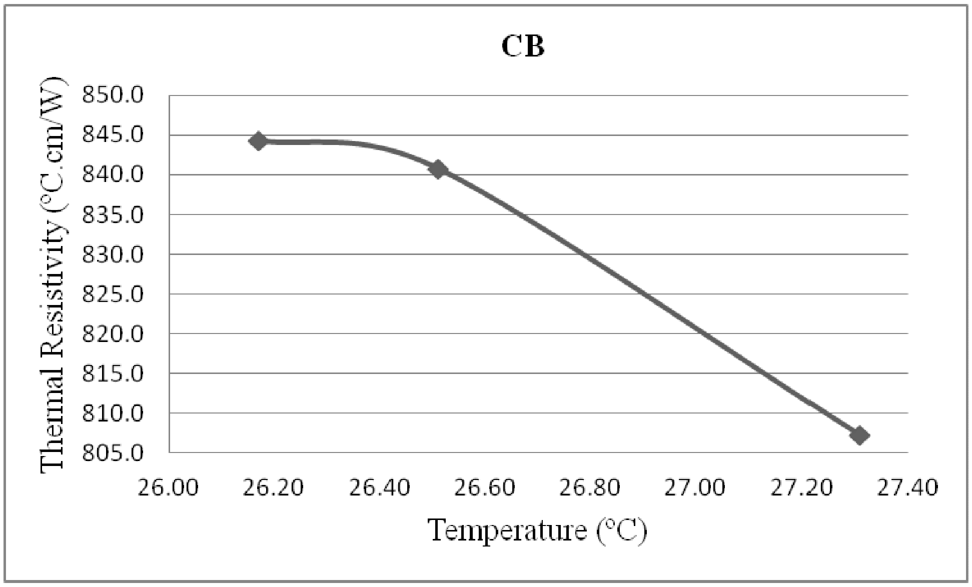

Figure 4.3 (b): Thermal resistivity of CB

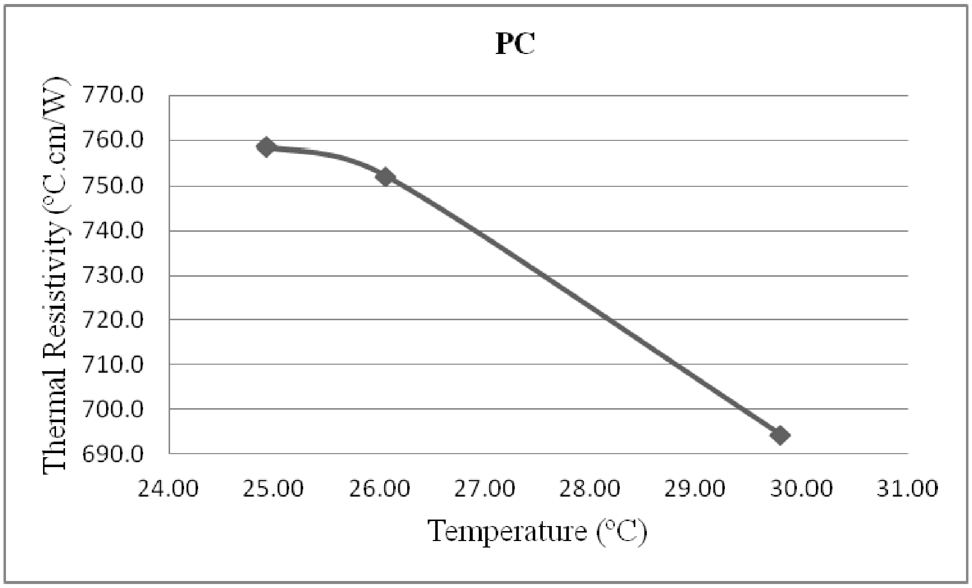

Figure 4.3 (c): Thermal resistivity of PC board

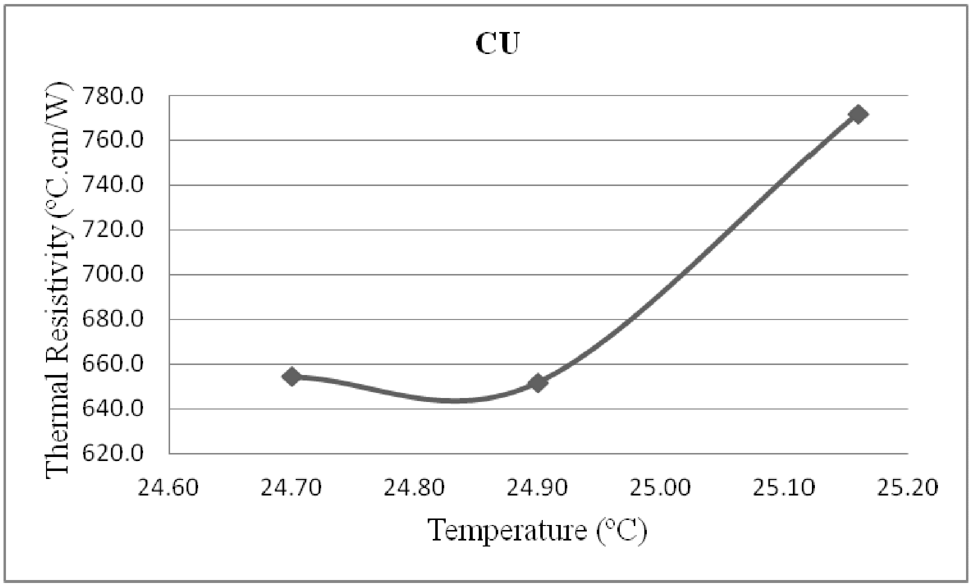

Figure 4.3 (d): Thermal resistivity of CU board

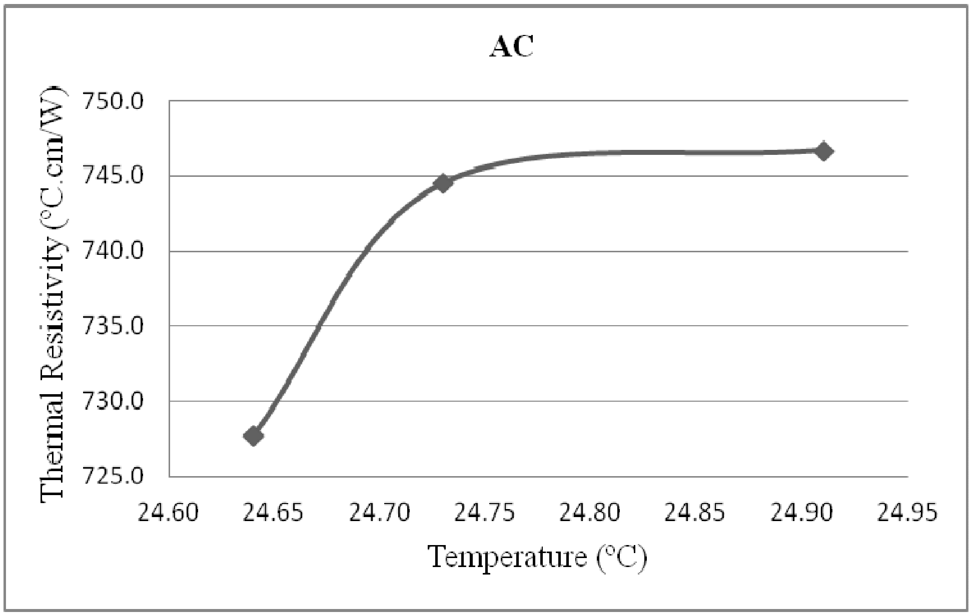

Figure 4.3 (e): Thermal resistivity of AC board

4.2.3.1 Comparison of Thermal Resistivity at 25ºC

All of the five samples of Medium Density Fiber (MDF) boards are then being obtained and compared with temperature at 25 ºC for thermal resistivity value. The result is shown as:

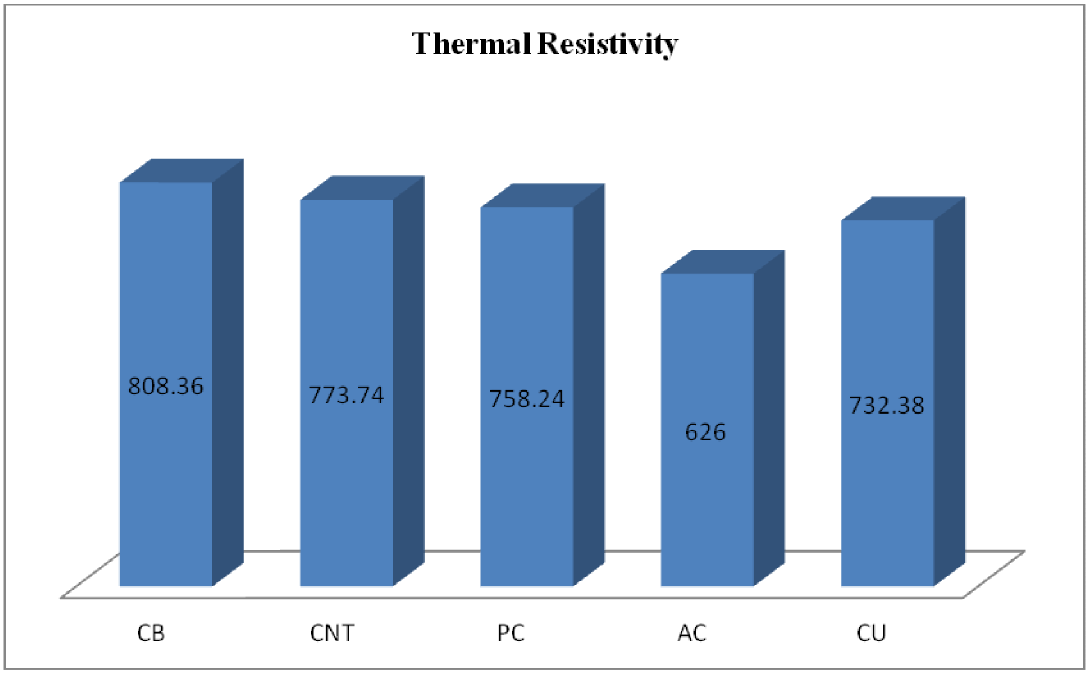

Figure 4.3 (f): Thermal resistivity of MDF boards at 25ºC

At 25ºC condition, all boards are stated thermal resistivity values with not much differences among them. This means that the values are nearly close.

4.2.4 Specific Heat

In the earlier research by Gammon (1987), he had concluded that the specific heat of wood-based materials as a function of temperature ranging between -30ºC to 140ºC. It has showed that specific heat is linearly varies with temperature. Table 4.4 shows the result of relationship between temperature and specific heat.

Table 4.4: Specific heat of MDF boards

Types	Temperature (ºC)	Specific Heat (MJ/m³.K)
Carbon Nanotube (CNT)	28.78	1.187
	27.35	1.181
	26.69	1.180
Control/Standard Board (CB)	27.31	0.861
	26.51	0.844
	26.17	0.837
Prepared Carbon (PC)	29.80	1.083
	26.06	1.036
	24.93	1.032
Copper (CU)	25.16	1.077
	24.90	1.222
	24.70	1.221
Activated Carbon (AC)	24.64	0.876
	24.73	0.882
	24.91	0.880

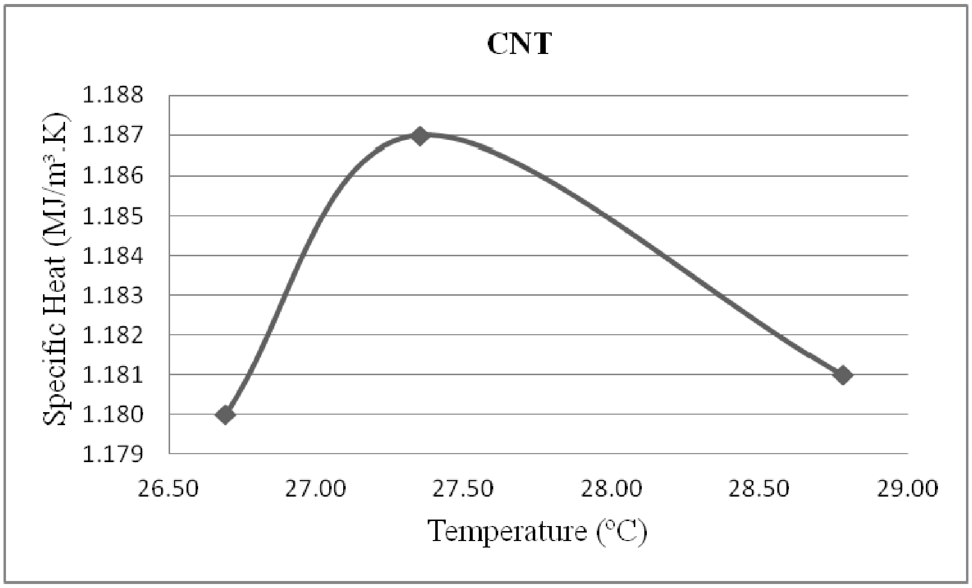

Figure 4.4 (a): Specific heat of CNT board

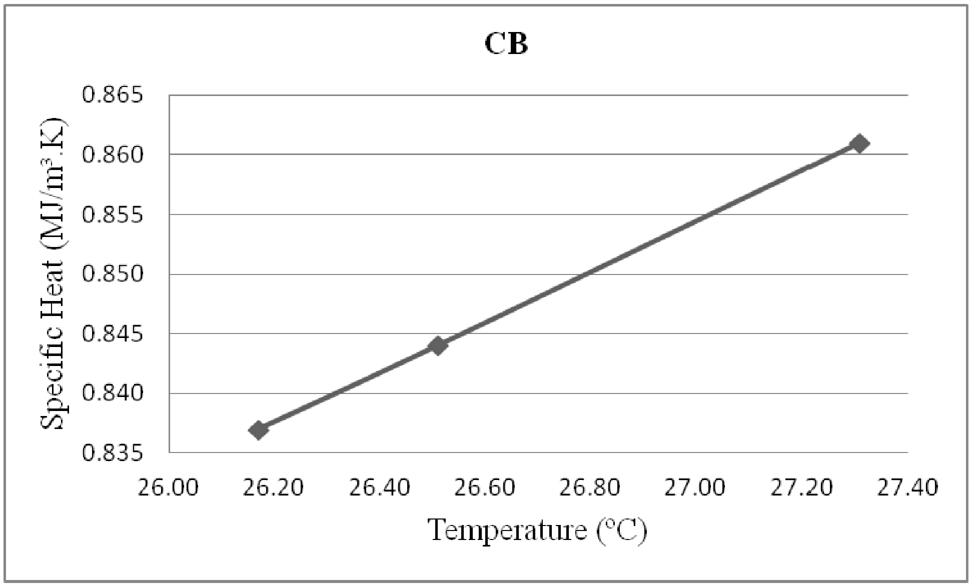

Figure 4.4 (b): Specific heat of CB

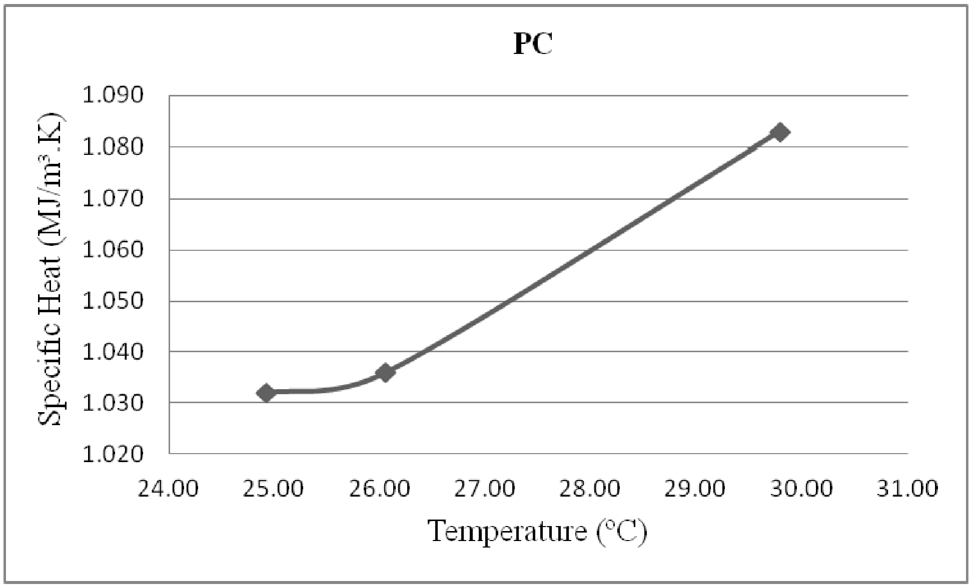

Figure 4.4 (c): Specific heat of PC board

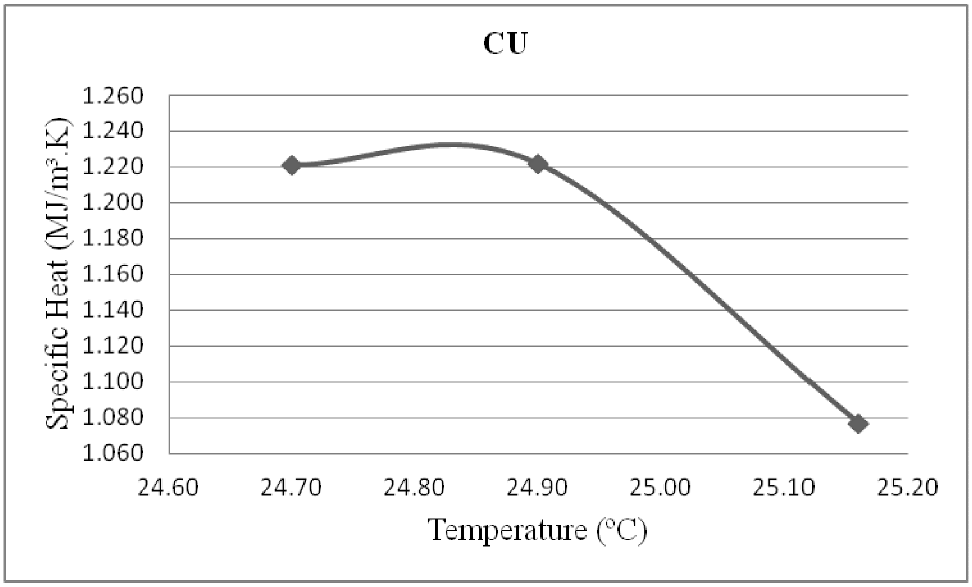

Figure 4.4 (d): Specific heat of CU board

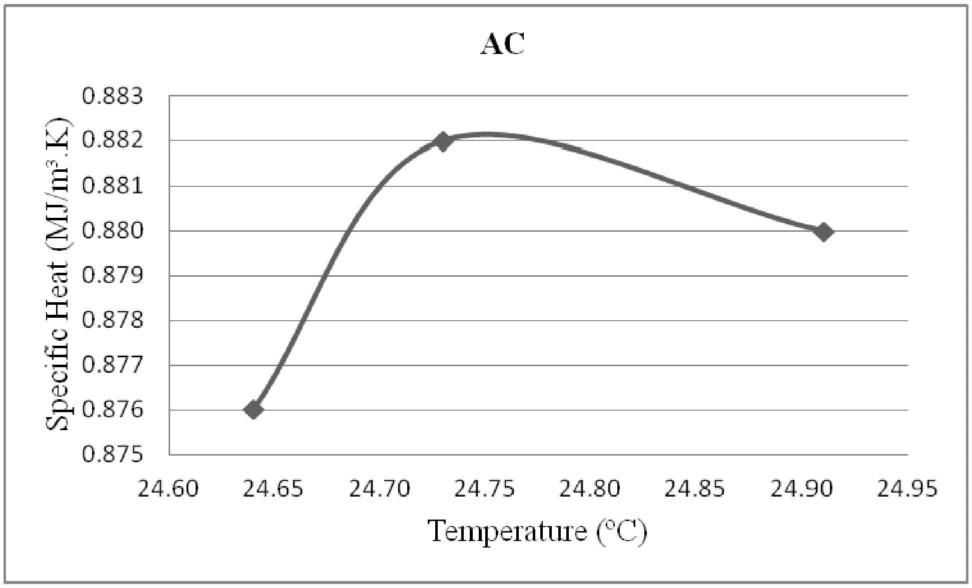

Figure 4.4 (e): Specific heat of AC board

4.2.4.1 Comparison of Specific Heat at 25ºC

All of the five samples of Medium Density Fiber (MDF) boards are then being obtained and compared with temperature at 25 ºC for thermal conductivity value. The result is shown as:

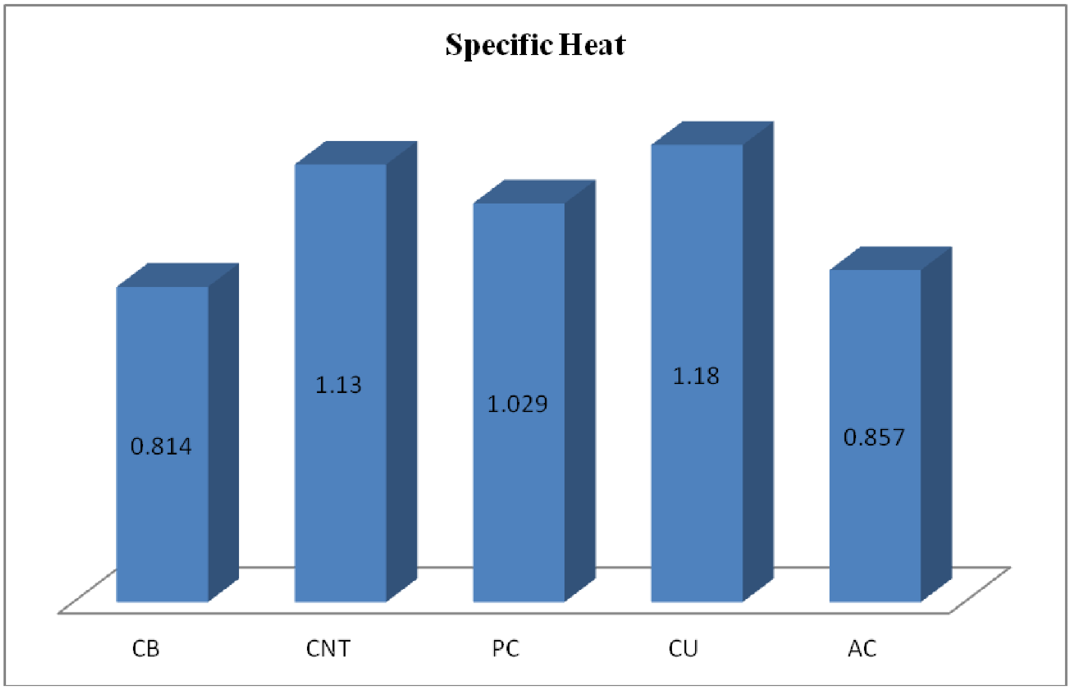

Figure 4.4 (f): Specific heat of MDF boards at 25ºC

For the specific heat obtained at 25ºC, copper board is given the best value which is 1.18 MJ/m³.K. Thus, the best material to choose is copper board. Carbon nanotube board is given the second best value which is then followed by prepared carbon board.

4.3 MECHANICAL TESTING

4.3.1 Brinell Hardness Test

Table 4.5: Brinell Hardness Number

Types	**Indentation Diameter, Di (mm)**	**Brinell Hardness Number**
Control/Standard Board (CB)	8.5	13.7249933
Carbon Nanotube Board (CNT)	8	16.2372611
Prepared Carbon Board (PC)	7	22.7208041
Copper Board (CU)	7	22.7208041
Activated Carbon Board (AC)	6	32.4745223

For Brinell Hardness Number, activated carbon board is giving the best number of hardness. Then, it is followed by prepared carbon and copper boards which are their hardness number values are same. Carbon nanotube is giving lower number of hardness.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter is mainly stated the conclusion that can be obtained from this project. The recommendations that can be implemented in the field of heat conduction is also stated in this chapter.

5.2 CONCLUSION

Generally, the relation between thermal properties of wood-based composites and temperature were studied in this project. Thermal properties like thermal conductivity, thermal resistivity, thermal diffusivity and specific heat volume are closely related to temperature. It has been observed that for most materials, thermal conductivity is increasing with the rising temperature. In other words, they are varying linearly. Meanwhile, the inverse of the thermal conductivity called thermal resistivity give the opposite result. The thermal resistivity is obtained as with the rising temperature, it will decrease. Same with the thermal conductivity, specific heat and thermal diffusivity are also increasing at the same time of the rising temperature. It can be concluded that temperature is a function of determining the thermal properties of wood-based materials. But, the hardness of the wood composites is giving a small number of hardness. Overall,the purpose of this project to determine the thermal conductivity of nanowood composite boards having different particle concentration has met its objective. The second objective which is to investigate heat conduction problem through wood composites has also being achieved.

5.3 FUTURE RECOMMENDATIONS

Manufacturing processes cost of carbon nanotube board is very high. Because of that, prepared carbon and activated carbon can be considered as new wood-based composites to use in the future. Their manufacturing cost is less than carbon nanotube and they have their own advantages. Even though their thermal properties is not good enough like carbon nanotube, but if they are mixing together with Urea-Formaldehyde (UF) resin, their thermal properties can be improved. The manufacturing process of these materials is also not complicated if compared to carbon nanotube.

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