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THE EFFECT OF TEMPERATURE AND GRAIN DIRECTIONS ON THE THERMAL CONDUCTIVITY OF WOODS

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ABSTRACT

A rig was designed to give accurate measurements of the effect of temperature and grain directions on the thermal conductivity of wood. Experimentations were done to evaluate the thermal conductivity of Mahogany, Agba and Melina woods, under steady-state conditions. Experiments were carried out within a distance of holes 20mm effort where thermometer probes were fixed. The heating element is a carbon-steel of 10mm thickness of 1000watts. Digital thermometer is instrumented on all grain structure directions during the experimentations on each tested wood sample. The heating element is electrically heated by varying the heat input with rheostat, at interval of 20 volts at 20 minutes heating. Experiments were run at different grain structure directions of heat flow between 15 to 180 watts. Results obtained were analyzed by calculating for the thermal conductivity K (w/m.^{o}C) in the directions of the grain for each sample. A dimensionless linear regression correlation equation were done, based on the thermal conductivity, K, and temperature, T. A linear regression, correlation was done in the range of temperature T , between 10 to 100^{o}C and thermal conductivity between 0.04 to 0.5 w/m,^{o}C.

Correlation for K with T: -

- $K = a + bT$
- $K = -0.4798 + 0.0409T, -0388 + 0.388T, -0.308 + 0.0316T$

(for Mahogany, Agba And Melina in Radial Direction)

Keywords**: Thermal conductivity, temperature, grain direction, heating, wood (Mahogany, Agba, and Melina)

1.0 INTRODUCTION

1.1 Nature of wood. Wood is a hygroscopic, porous material. The unique structure of wood causes the anisotropic nature of wood in its mechanical and physical properties. Thermal conductivity of wood has been studied by many scientists.

The ability of a material to conduct heat as a result of transmitting molecular vibrations from one atom or molecule to another varies greatly depending upon the chemical nature of the material and its gross structure and texture. The thermal conductivity of wood varies in the three main directions of wood as they are usually referred to in the wood lumber industry – Longitudinal direction (parallel to the grain, along the length of a tree), Radial direction, (perpendicular to the grain, along the radius of the cross section) and Tangential direction (perpendicular to the gain, tangent to each growth ring).

The grain structure of wood in these three directions is different. Most of the anisotropic properties of wood are due to this structure difference.

The thermal conductivity of Mahogany and Agba (*hard wood*) and Melina (*in-between hard and soft*) are all in their grain directions. Their thermal conductivity was determined for all three directions (radial, tangential and longitudinal) depending on a number of factors with varying degree of importance. The more significant variable affecting the rate of heat flow in these woods are (1) Density of wood (2) Moisture content of wood (3) Direction of heat flow with respect to the grain. (6) Extractives or chemical substances in the wood and defects, etc.

1.2 Wood Grain (*Anatomical*) Structure

The thermal conductivity of wood is structure dependent property. It varies in the three main directions of wood as they are usually referred to in the wood industry - longitudinal direction (parallel to the grain, along the length of a tree), radial direction (perpendicular to the grain, along the radius of the round tree on the cross section), and tangential direction (perpendicular to the grain, tangent to each growth ring). The anatomical structure of wood in these three directions is different. And, most of the anisotropic properties of wood are due to this structure difference.

The majority component of softwood species is long slender cells called longitudinal trachieds, which occupy about 90-95% of the total wood volume Haygreen and Bowyer. On the cross section of a tree, they are close to rectangular shape with different cell wall thickness. Trachieds that are formed early in a growing season are thin-walled cell with greater diameter, while those formed later in the year are thick-wall with smaller diameters. Tracheid give softwood the mechanical strength required (especially the thick-walled latewood tracheids) and provide for heat and mass transport. The heat transfer in wood is mainly by conduction through the cell walls, and only a few on the tangential walls Gronli reported that there are about 200 pits on each early wood tracheid and only 10-50 rather small bordered pits on each latewood tracheid. Another important type of cells in softwood are ray cells, which include ray tracheid and ray parenchyma arranging in radial strands perpendicular to the grain direction. Softwood ray are from one to many cells in height but are usually only one cell wide. Ray cell are small compared to the longitudinal tracheids, Resin canals are another characteristics for the softwood species, especially in pine. One typical softwood genus in pine, southern yellow pine is a popular species group for construction application in America, and scots pine is a popular species for the European construction industry.[19]

Comparing to the softwood structure, hardwood structure is much more complex. Hardwood are composed of more diverse type of cells, more varied arrangement of cells and varied size of rays. One major type of cells is the specialized conducting cell called vessel element. They are very large in diameter with very thin walls. Fiber is another major type of cells with very thick walls in hardwoods. All the vessels and fibers tend to be rounded in the cross section as compared to the nearly rectangular shape of softwood tracheid. Hardwoods are characterized by very large rays, which have a significant effect on some of the physical properties of wood. In general, comparing the softwood with hardwood structure, the softwood is more homogenous while the hardwood is relatively heterogeneous.

Differential shrinkage and swelling in the three main directions of wood lumber and different mechanical and physical properties in the three directions have been shown to be all related to the orientation of structural units of the cell wall Wargaard. The orientation of fibrils in the cell walls of wood has shown accurately for the greater part of the variation in thermal conductivity values predicted on the basis of specific gravity and moisture content. Cell wall structure is characterized with 3 layers. The outer and inner layers are very thin compared to the middle layer of the secondary wall. (S2). The S2 layer takes about 90-95% of the whole cell wall. So it plays the major role in materials properties. The micro-fibrils in the S2 layer are oriented from 10^o to 30^o from the cell axis, and are nearly parallel to the long axis of the cell when observed under the microscopic. This orientation is responsible for the significant difference on a lot of physical properties between the longitudinal and transverse direction, such as thermal conductivity. Wargaard showed that the transverse thermal conductivity deviations in Douglas-fir are greatly dependent on the variation of micro-fibril slope. [20]

Cell wall substance plays an important roll in material properties. Wood anisotropic material properties and shrinkage has been demonstrated to be related to the cell wall amount and structure in the wood Skaar and Pentony. They found that variations in shape of cell cross section and wall thickness has an influence on anisotropy of shrinkage. Trenard and Guenean pointed out that differential shrinkage is more closely related to certain aspect of cellular structure, e.g. lumen dimensions and cell wall thickness. Wood density has a close relation with the cell wall percentage in the wood samples. Their results showed that density was influences more by the radial than by the tangential component of both tracheid width and cell wall thickness. Excellent relationships were found between density and proportion of cell wall on tracheid cross section data, and he also proved that the maximum density was mainly controlled by the cell wall thickness. Cell wall thickness in a single cell and between earlywood and latewood cells is also different.[22]

Nobuchi et al used a pinning method to investigate the differentiating zones in the cell wall structure. The cell wall structure which suffered direct effects of pinning injuries in stems of Crytomenia japonica was observed under an ordinary light microscope. They found that the tangential wall thickness of tracheid was thicker than that of the radial wall in the early wood area, but thinner than the radial wall thickness for the latewood tracheids. The different cell wall thickness and structure in the radial and tangential directions can be correlated with the different properties in the two directions. [23]

In terms of the influence of the gross wood structure upon the thermal conductivity, Wargaard did a study examining the effect of thee type, size and disposition of the longitudinal cells on the physical property. His results failed to show the significant effect from these gross structures.

1.3 **Conduction of Heat Transfer**

(One dimensional)

When a temperature gradient exists in a body, experience has shown that there is an energy transfer from the high-temperature region to the low-temperature region. We say that the energy is transferred by conduction and that the heat-transfer rate per unit area is proportional to the normal temperature gradient:

$$\frac{q}{A} \ \alpha \ \frac{\partial T}{\partial x} \ .$$

When the proportionality constant is inserted

$$q = k\,A\,\frac{\partial T}{\partial x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.1$$

where q is the heat-transfer rate and $\partial T/\partial x$ is the temperature gradient in the direction of heat flow. The constant k is called the thermal conductivity of the material, and the minus sign is inserted so that the second principle of thermodynamics will be satisfied i.e. heat must flow downhill on the temperature scale, as indicated in the coordinate system of *figure 1*

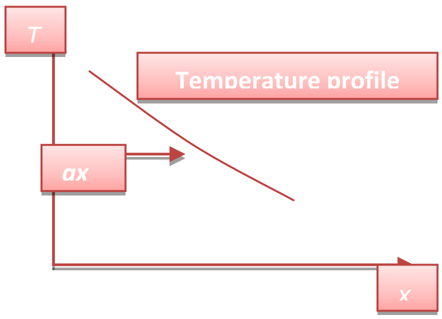


Fig 1.1

Equation 1 is called Fourier's law of heat conduction after the French mathematical physicist Joseph Fourier, who made very significant contributions to the analytical treatment of conduction heat transfer. It is important to note that equation *1* is the defining equation for the thermal conductivity and that k has the units of watts per meter per Celsius degree in a typical system of unit ion which the heat flow is expressed in watts.

We now set ourselves the problem of determining the basic equation that governs the transfer of hat in a solid, using equation *1* as a starting point.

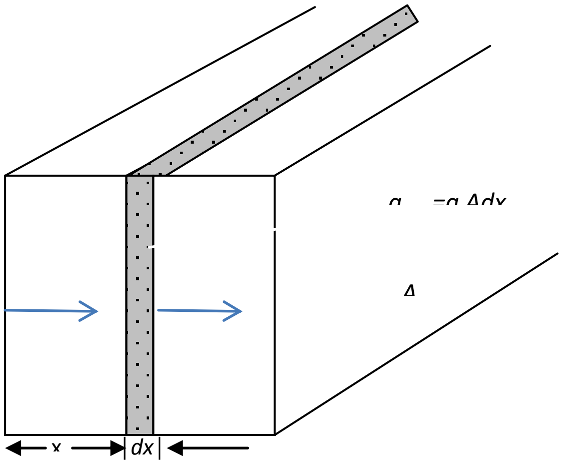


Fig1.2

Element volume for one-dimensional heat-conduction analysis

1.4 Thermal Insulation

- Thermal insulation refers to the material used for the purpose of reducing the rate of heat flow. Thus its distinguishing features is low thermal conductivity, which has been defined as the time rate of heat flow through unit area of homogenous substances under the influence of a unit temperature gradient in the direction perpendicular to the area. "Thermal conductivity is measured in $J/Sec.m^2$ $(Btu/(hr)(ft^2)$ Thermal conductivity varies with temperature and must be quoted at a specific mean temperature.

- To increase the comfort of living spaces
- To converse heat or some other forms of energy e.g. electrical energy to operate a refrigerator compressor.
- To facilitate control of the temperature of a process.
- To reduce the temperature of the shell of a pressure vessel.
- To control the external temperature of the insulated space in order to avoid danger to personnel.
- To protect the surrounding structural members from damage by high temperature
- To reduce the temperature of working spaces and in the case of equipment operating below ambient temperatures to prevent condensation or icing at the warmer surface.
- Depending on the application, one or the other purpose may govern the choice of insulation.

1.5 Thermal Conductivity of Wood

Wood is a hygroscopic, porous material. The unique structure of wood causes the anisotropic nature of wood in its mechanical and physical properties. Thermal conductivity has been shown by many scientists to have a very close relationship with the wood structure and moisture. The ability of a material to conduct heat as a result of transmitting molecular vibrations from one atom or molecule to another varies greatly depending upon the chemical nature of the material and its gross structure or texture. Thermal conductivity, k, is expressed in terms of quantity of heat, *Q* that flows across unit thickness *x*, of a material with a unit cross section, A under unit temperature difference between the two faces, T, in unit time, t:

$$k = \frac{Q * x}{A*T*t} \quad \ldots\ldots 1.2$$

The heat conductivity of wood is dependent on a number of factors with varying degree of importance. The more significance variables affecting the rate of heat flow in wood are ; 1) Density of wood; 2) moisture content of wood; 3) direction of heat flow with respect to the grain; 4) relative density; 5) extractives or chemical substances in the wood, and defects, etc. from numerous and varied factors affecting thermal conductivity of wood, Van Dusen first found that there was nearly a linear relationship between conductivity and density. So did Rowley.

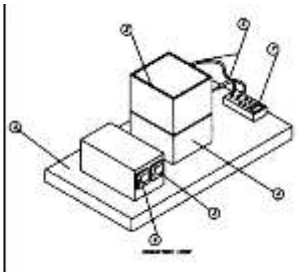
2.0 DESIGN AND CONSTRUCTION OF THE RIG.

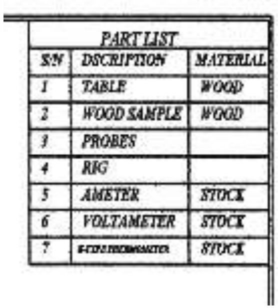
1.1 Overview of Rig

- The design of the system is single sided. It is capable to test one fixed size specimen at a time. The system uses “electric heating element method” to determine the thermal conductivity of insulators and other materials of higher thermal resistance. The size and shape of the sample is historically similar to that of a standard brick with an equal companion piece used for thermal symmetry. An electric circuit is also available for regulating the heat entering the heater (electric heating element) and for reading the different values of the voltage and current entering the system. The outside body and inner chamber are fully lagged while leaving the top of the system open to ensure heat flows in one direction. There also provision of k-type digital thermometer and two k-type digital thermometer probe for measuring and taking the readings of the temperature.

2.1 **The rig:**

The material used for construction of the entire body of the rig is mild steel. In other words, the materials have the same material properties in its entire body. The steel was made by oxidizing away the impurities that are present in iron produced in the blast furnace. Mild steel is a ferrous metal because it contains iron which is the major constituent and most times it forms the major component in mechanical production.





PART LIST		
S/N	DSCRIPTION	MATERIAL
1	TABLE	WOOD
2	WOOD SAMPLE	WOOD
3	PROBES	
4	RIG	
5	AMETER	STOCK
6	VOLTAMETER	STOCK
7	K-TYPE THERMOMETER	STOCK

Fig 2.1

The outer and inner chamber was coupled together with the aid of welding, bolts and nuts. The heating sources was fixed on the top of the inner chamber while the top of the chamber was covered with light steal plate and left unlagged for the flow of heat. Meanwhile, the entire chamber both in and out was fully lagged. Inner chamber was lagged using brick and fiber glass while the outer was lagged using fiber glass and asbestos clothing (which was used to hold the fiber glass of rig). The dimension of the rig is 180mm and 130mm of the length and breath respectively the height of the rig is 100mm.

2.1.1 The electric heating element:

The electric heating element with power capacity of 1000 watts and voltage of 240 volts was fixed in the inner chamber with its wire extended out of the inner chamber to the electric circuit.

2.2 **Synthesis**

This is breaking down of the main system to reveal smaller elements for analysis. This is to enable the uncoupling of hidden problems not envisaged. For instance the uncoupling of this system reveals the existence of smaller elements such as the electric heating element, holder's flanges, bolts and nuts, fiber glass, bricks used in the inner chamber.

2.2.1 Holders:

The holders were made of mild steel. They were used to hold the electric heating element in place with the aid of bolts and nuts in the inner chamber

2.2.2 Fasteners:

The fasteners employed are bolts and nuts. This kind of fasteners was used in order to allow easy uncoupling in future in case of any fault. Thus the system was designed to have a temporal joint.

2.2.3 Fiber glass and asbestos materials:

Fiber glass was used in lagging the entire both the rig and the wood sample while the asbestos is the lagging material used in holding the fiber glass to the wall of the rig as well as lagging the system and wood samples. They are insulators used also to prevent heat lose. They are used to lag the entire outside body of the system except the top of the system which was left open. The selection of insulation strictly depends on its conductivity; types, shapes and form of insulation.

2.2.4 Digital thermometer:

A K-type digital Thermometer with two probes measure the temperature difference. It is known as temperature indication.

2.2.5 Electric circuit:

These consist of Voltmeter, ammeter and rheostat. These instruments are used to measure the voltage and the electric current going into the electric heating element. The readings from voltmeter and ammeter helps in calculation of the heat flow through the body of the sample Q;

$$Q = IV \quad \ldots\ldots 2.1$$

2.2.6 Voltmeter:

This measures, the voltage of the current that enters into the system. An analog AC voltmeter of range 0 – 500 volts was used to measure the voltage that enters into the heating system.

2.2.7 Ammeter:

This measures the amperage. An analog AC ammeter of 0–25 amps, measurement range was used to measure the current that is supplied to the heating element. This gives us the value of I in the equation.

2.2.8 Rheostat:

This is use to regulate the voltage of the current that enters into the system. It is use to regulate the voltage so that the test piece won't get burnt.

2.3 The Wood Sample

The woods were cut out from the source and machined to a given profile. This process was achieved with the aid of a machine cutter with an adjustable horizontal blade. After cutting, the length and width of the woods are 0.18m and 0.13m respectively. The wood was reduced to a thickness of 0.13m with the aid of a wood saw or smoother.

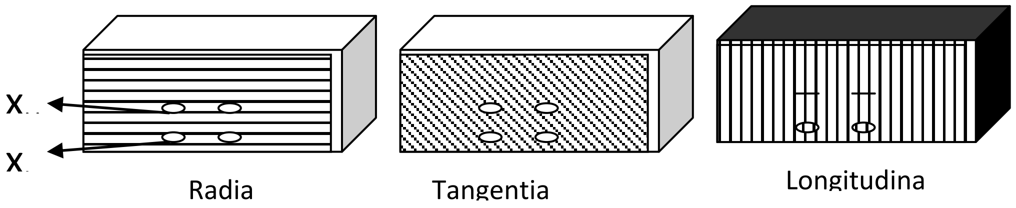
The different wood sample or test piece selected for the tests include:

Mahogany, Agba and Melina. The sample were cut into rectangular box shape. The length and width of the wood samples is 180mm by 130mm while the thickness is 130mm.

Four tiny holes of diameter 5mm and 70mm depths were drilled in the wood sample. Four holes on ach sample considering the grain structure direction. Two holes up and three holes down, all the holes are 50mm apart. The two lower holes sample while the two upper holes are of the same height from the bottom of the wood sample as well. The lower holes on the radial grain direction for each wood samples is label x_{L1} and x_{L2} while the upper holes are labeled x_{H1} and x_{H2}.

On the other side, for longitudinal grain direction, the lower holes are labeled y_{L1} and y_{L2}, while the upper holes are labeled y_{H1} and y_{H2}.

The holes for tangential grain direction has Z denotations; these holes are the point from which temperature readings are taken while the x_L, x_H, y_L, y_H, z_L and z_H are the height or distance at which temperature readings are taken. x_L, y_L, and z_L is 30mm from the bottom of the wood sample, x_H, y_H, and z_H is 50mm from the bottom of the sample; d_x, d_y, and d_z is20mm.



wood sample in grain structure directions

Fig 2.2

Longitudinal direction (parallel to the grain, along the length of a tree), radial direction (perpendicular to the grain, along the radius of the round tree on the cross section), and tangential direction (perpendicular to the grain, tangent to each growth ring).

: Set up wood sample in laboratory

Fig 2.3

2.4 Experimental Procedure / Data

- The rig was plugged to the source of power. The lagged wood sample is placed on top of the rig. The thermometer probes which were connected to the digital thermometer for taking the temperature reading is inserted into each of the X_L and the corresponding X_H. The rig is then switched on and the voltage is regulated by the rheostat to 40 volts. The ammeter reading is also taken for the corresponding current before heating the atmospheric temperature was taken. The wood sample is allowed to heat for 20 minutes and temperature at X_L and the corresponding X_H are taken from the digital thermometer. This same test was carried on each of the four holes drilled on the sample of the wood in X (radial grin direction) using the same procedure.
- The same procedure or process was repeated when the voltage was increased to 60 volts, 80 volts, 100volts, 120 volts, 140 volts and 160 volts and their corresponding current for the same grain structure direction.
- This experiments was carried out on radial grain structure direction X longitudinal grain structure direction Y and tangential grain structure direction Z

3.0 EXPERIMENTAL RESULTS

The results of experiment/test are shown in tables below

Table 3.1: Radial Grain Direction for Mahogany

S/N	**V** *Volts*	**I** *Amp*	**Q** *watts*	T_{L1} ^{o}C	T_{L2} ^{o}C	T_{LM} ^{o}C	T_{HI} ^{o}C	T_{H2} ^{o}C	T_{HM} ^{o}C	T_{LM}-T_{HM} **(*dT*)** ^{o}C
1	40	0.4	16	37	37	37	26	26	26	11
2	60	0.5	30	40	40	40	26	26	26	14.
3	80	0.6	56	42	43	42.5	27	27	27	15.5
4	100	0.7	80	45	45	45	27	28	27.5	17.5
5	120	0.8	96	49	48	48.5	28	28	28	20.5
6	140	0.9	126	52	52	52	30	30	30	22
7	160	1.1	17.6	53	56	54.5	31	32	31.5	23

Table 3.2: Radial Grain Direction for Agba

S/N	**V** *Volts*	**I** *Amp*	**Q** *watts*	T_{L1} ^{o}C	T_{L2} ^{o}C	T_{LM} ^{o}C	T_{HI} ^{o}C	T_{H2} ^{o}C	T_{HM} ^{o}C	T_{LM}-T_{HM} **(*dT*)** ^{o}C
1	40	0.4	16	38	39	38.5	26	26	26	12.5
2	60	0.5	30	41	40	40.5	26	27	26.5	14
3	80	0.6	56	43	43	43	27	27	27	16.5
4	100	0.7	80	47	47	47	28	28	28	19
5	120	0.8	96	50	50	50	28	29	28.5	21.5
6	140	0.9	126	53	53	53	30	30	30	23
7	160	1.1	176	56	55	55.5	32	31	31.5	24

Table 3.3: Radial Grain Direction for Melina

S/N	**V** *Volts*	**I** *Amp*	**Q** *watts*	T_{L1} ^{o}C	T_{L2} ^{o}C	T_{LM} ^{o}C	T_{HI} ^{o}C	T_{H2} ^{o}C	T_{HM} ^{o}C	T_{LM}-T_{HM} **(*dT*)** ^{o}C

1	40	0.4	16	41	41	41	27	26	26.5	14.5
2	60	0.5	30	45	44	44.5	27	28	27.5	17
3	80	0.6	56	47	47	47	28	28	28	19
4	100	0.7	80	50	50	50	29	29	29	21
5	120	0.8	96	53	53	53	30	29	29.5	23.5
6	140	0.9	126	56	55	55.5	31	30	30.5	25
7	160	1.1	176	59	59	59	33	31	32	27

3.1 **Analysis Of Result**

3.1.1 Sizes of the wood

1) **Length of wood =180mm**
2) **Width of wood = 130mm**
3) **Height of wood= 130mm**

Volume of wood sample

$$V = L \text{ x } W \text{ x } H \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

$$= 0.18 \text{ x } 0.13 \text{ x } 0.13$$

$$= 0.003042\text{m}^3$$

$$\textit{Density } \rho = \frac{\textit{Mass x 1000}}{\textit{Volume}}$$

Density of the wood samples ρ

$$\rho = \frac{Mass}{Volume} \text{ x } \frac{1000}{1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

1) *Mahogany* $= \rho = \frac{2.35}{0.003045} \text{ x } \frac{1000}{1}$

$$= 771756.98\text{kg/m}^3$$
$$= 7.72 \text{ x } 10^5\text{kg/m}^3$$

2) *Agba* $= \rho = \frac{2.30}{0.003045} \text{ x } \frac{1000}{1}$

$$= 755336.62\text{kg/m}^3$$
$$= 7.55 \text{ x } 10^5\text{kg/m}^3$$

3) *Melina* $= \rho = \frac{2.05}{0.003045} \text{ x } \frac{1000}{1}$

$$= 673234.81\text{kg/m}^3$$
$$= 6.73 \text{ x} 10^5\text{kg/m}^3$$

3.2 LINEAR REGRESSION CORRELATION OF K AND T

From the Fourier equation of thermal conductivity

$$K = \frac{Q}{A} \times \frac{dx}{dT}$$

$$K = n + mT,\ K = a + bT$$

$$y = a + bx$$

where $m = b$

$n = a$

apply liner regression equation

$$y = bx + a$$

where :

$$b = \frac{n\Sigma xy - \Sigma x\Sigma y}{n\Sigma x^2 - (\Sigma x)^2}$$

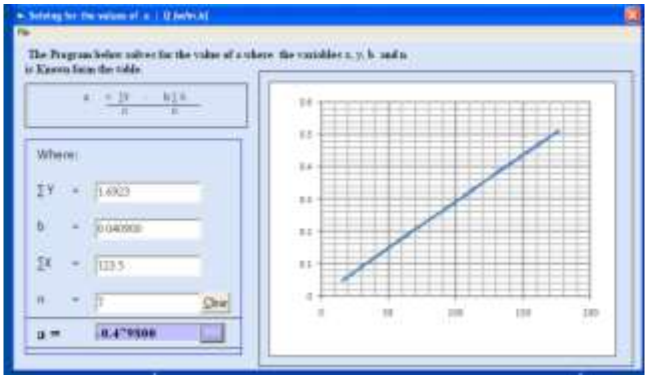
$$a = \frac{\Sigma y}{n} - \frac{b\Sigma x}{n}$$

$$r = \frac{n\Sigma xy - \Sigma x\Sigma y}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]}}$$

3.3 Linear Regression Correlation Of K (Thermal Conductivity) W/M,^{O}c And T (Temperature) ^{O}c

Fig3. 1: *Program Control Interface*

Program Calculation for (a)



The Program below solves for the value of a where the variables x, y, b and n is Known from the table

$a = \frac{\Sigma Y}{n} - \frac{b\Sigma X}{n}$

Where:

ΣY = 1.6923

b = 0.040900

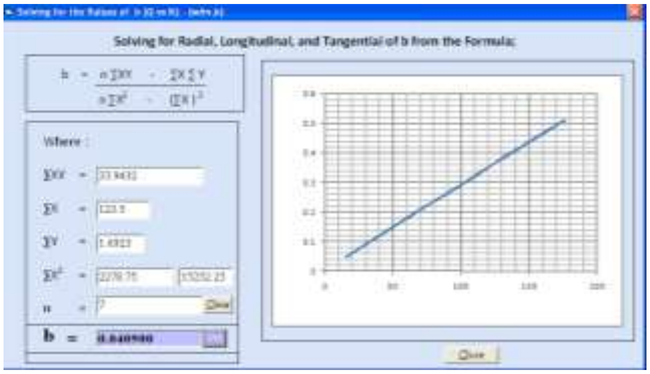
ΣX = 123.5

n = 7

a = -0.479500

Fig 3.2: *Program interface for calculating of (a)*

Program Calculation for (b)



Solving for Radial, Longitudinal, and Tangential of b from the Formula:

$$b = \frac{n\sum XY - \sum X\sum Y}{n\sum X^2 - (\sum X)^2}$$

Where :

$\sum XY$ = 33.9432

$\sum X$ = 123.5

$\sum Y$ = 1.6923

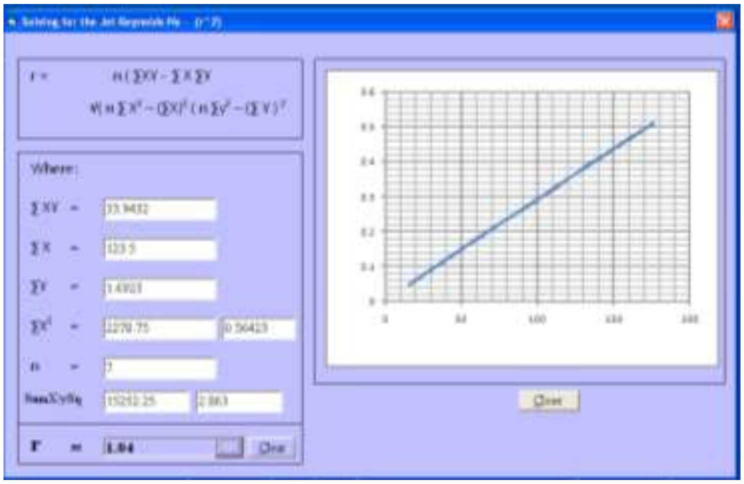
$\sum X^2$ = 2278.75 15252.25

n = 7

b = [illegible]

Fig 3.3: *Program interface for calculating of (b)*

Program Calculation for (r)



$$r = \frac{n(\sum XY) - \sum X\sum Y}{\sqrt{(n\sum X^2 - (\sum X)^2)(n\sum Y^2 - (\sum Y)^2)}}$$

Where:

$\sum XY$ = 33.9432

$\sum X$ = 123.5

$\sum Y$ = 1.6923

$\sum X^2$ = 2278.75 0.56423

n = 7

SumXySq 15252.25 2.863

r = 1.04

Fig 3.4: *Program interface for calculating of (r)*

4.0 EFFECT OF TEMPERATURES ON WOODS AT RADIAL GRAIN DIRECTIONS

Table 4.1: *Linear regression for mahogany in radial direction*

MAHOGANY

S/NO	dT = X (°C)	K = Y ((w/m/ °C)	X^2	Y^2	XY
1	11	0.048	121	0.002304	0.528
2	14	0.0893	196	0.007974	1.2502
3	15.5	0.166	240.25	0.027556	2.573
4	17.5	0.235	306.25	0.055225	4.1125
5	20.5	0.279	402.25	0.077841	5.7195
6	22	0.365	484	0.133225	8.03
7	23	0.51	529	0.2601	11.73
∑	123.5	1.6923	2,278.75	0.564225	33,9432

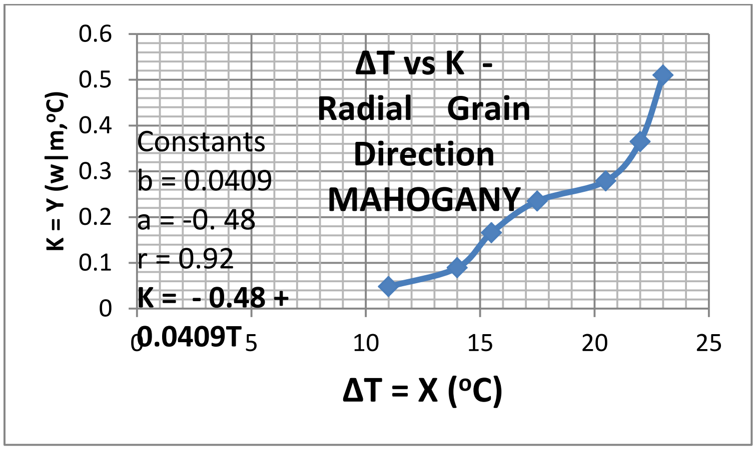


Fig. 4.1: Linear regression correlation of k= a+bT for mahogany on radial grain direction

Table 4. 2: *Linear regression for Agba in radial direction*

AGBA

S/NO	dT= X (°C)	K = Y ((w/m/ °C)	X^2	Y^2	XY
1	12.5	0.0479	156.25	0.002294	0.59875
2	14	0.0891	196	0.007939	1.2474
3	16.5	0.165	272.25	0.027225	2.7225
4	19	0.234	361	0.054756	4.446
5	21.5	0.2786	462.25	0.077618	5.9899
6	23	0.364	529	0.132496	8.372
7	25	0.506	625	0.256036	12.65
∑	131.5	1.6836	2,601.75	0.558364	36.02655

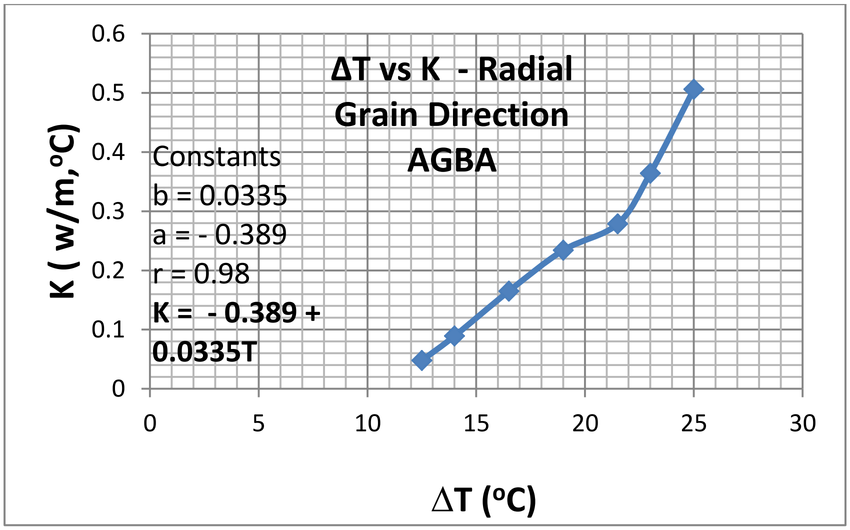


Fig.4.2: Linear regression correlation of k= a+bT for Agba in radial grain direction

***Table 4.3:** Linear regression for Melina in radial direction*

MELINA

S/NO	dT = X (°C)	K = Y (w/m/ °C)	X^2	Y^2	XY
1	14.5	0.04759	210.25	0.002265	0.6901
2	17	0.088	289	0.007744	1.496
3	19	0.163	361	0.026569	3.097
4	21	0.232	441	0.053824	4.872
5	23.5	0.276	235	0.076176	6.486
6	25	0.361	625	0.130321	9.025
7	27	0.502	729	0.252004	13.554
∑	147	1.6696	2,890.25	0.548903	39.2201

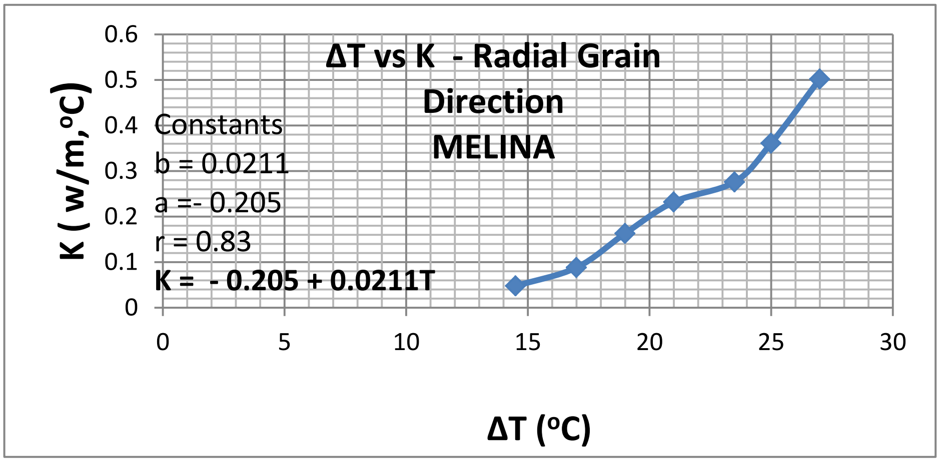


***Fig 4.3:** Linear regression correlation of k= a+bT for Melina in radial grain direction*

5.0 Comparison of The Experimental Result

Table 5.1 of graph figure 5.1 depicts that the range of *K* of Mahogany is 0.048 to 0.51 *w/m°C*, Agba 0.0479 to 0.506 *w/m°C* and Melina 0.0476 to 0.502 *w/m°C*. It is therefore deduced that Mahogany has highest thermal conductivity followed by Agba, and then Melina under radial tests experiment.

Table 5 .1: Table of K of the wood Samples in Radial Grain Direction

S/NO	ΔT (°C)	K - (w/m,°C) - Mahogany	K - (w/m, °C) - AGBA	K - (w/m, °C) - MELINA
1	12	0.048	0.0479	0.0476
2	14	0.0893	0.0891	0.088
3	16	0.166	0.165	0.163
4	18	0.235	0.234	0.232
5	20	0.279	0.278	0.276
6	22	0.368	0.364	0.361
7	24	0.51	0.506	0.502

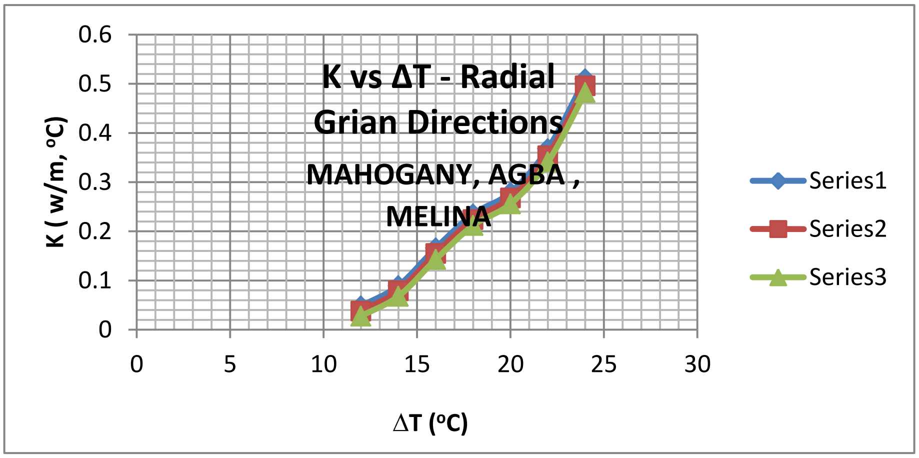


Figure 5.1: *K vs ΔT radial direction for the three samples*

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