THE EFFECT OF GRAIN ANGLE AND SPECIES ON THERMAL CONDUCTIVITY OF SOME SELECTED WOOD SPECIES

Fatih Yapici,[a,]* Ayhan Ozcifci,[a] Rasit Esen,[a] and Seref Kurt [a]

In this study the thermal conductivity of different wood materials was determined. For this purpose, Scots pine (*Pinus sylvestris* L.), *Uludag fir* (*Abies Bornmülleriana* Matff), Oriental beech (*Fagus orientalis* L), Oak (*Quercus robur* L.), and Chestnut of Anatolia (*Castanea sativa* Mill.) woods were used. In the test, the thermal conductivity of the woods was measured according to procedure of ASTM C 1113-99 standards. The lowest thermal conductivity was obtained in the perpendicular direction of Scots pine samples as 0.156 Kcal/mh°C. The highest thermal conductivity was obtained from perpendicular direction of samples in Oriental beech as 0.331 Kcal/mh°C.

Keywords: Thermal conductivity; Perpendicular direction; Parallel direction; Wood material; Grain angle

Contact information: a University of Karabuk, Technical Education Faculty, Karabuk 78050 Turkey
** Corresponding author: fyapici@karabuk.edu.tr*

INTRODUCTION

Wood can be defined as a natural composite material, lignocellulose, which is comprised of components having different chemical nature. Due to temperature variations, the crystalline structure of cellulose chains may be altered, resulting in permanent loss in strength and considerable changes in physical behavior, including its ability to conduct heat (Avramidis 1992).

Wood also can be described as a non-isotropic material; thus thermal conductivity in the fiber direction has been reported to be 2 to 3 times higher than the perpendicular and parallel directions (Takegoshi et al. 1982). It is well known that the effective thermal conductivity of a wood specimen is affected by its moisture content (Yokende 1990). Thermal properties of wood are needed in applications such as fuel conversion, building construction, and other areas of industry (Kamke and Zylkowski 1989).

In addition, wood can be described as a porous material. Porosity is a parameter that is likely to affect magnitude as well as the temperature dependence of the thermal properties.

Several researchers have developed measurement methods known as the transient hot wire transient line source method (Glatzmaier and Ramirez 1985; Backstrom 1982; Cull 1974), the transient hot strip, and the transient plane source techniques (Gustafsson et al. 1979; Gustafsson 1991). Variations of the transient hot wire (THW) and transient line source (LST) techniques have been developed to measure the thermal conductivities of building materials. A large number of building materials such as concrete, gypsum plaster, mortars, wood, concrete, etc., are highly heterogeneous and porous composite materials (Morabito 1989).

Most published thermal conductivity measurements on wood samples have been carried out with standard hotplate devices, in which the test samples were placed under constant conditions for sufficient length of time to insure a uniform temperature gradient throughout the sample. The temperatures of the test surfaces was recorded and the rate of the heat flow was calculated from the electric input to the heating element (MacLean 1941; Skaar 1988).

In a similar study, Uysal et al. (2008) found that some fire retardant treatments affected the thermal conductivity of poplar wood. When they compared un-impregnated and impregnated test samples, the highest value was obtained in poplar wood that had been impregnated with boric acid.

The aim of this study was to determine of effect of grain angle and wood species on thermal conductivity.

MATERIAL AND METHODS

Wood Materials

A special emphasis was put on the selection of wood material. Accordingly, clear, defect-free, knotless, normally grown (without zone line, reaction wood, or decay) wood species growing locally were selected. As raw materials, Scots pine (*Pinus sylvestris* L.), Uludag fir (*Abies Bornmülleriana* Matff), Oriental beech (*Fagus orientalis* L), Oak (*Quercus robur* L.), and Chestnut of Anatolia (*Castanea sativa* Mill.) woods were used.

Preparation of the Test Samples

The wood samples, which were cut only from sapwood, were conditioned at 20±2°C and 65±3 % relative humidity until their weights became stable by holding them for 8 weeks in a conditioning room. In total 100 samples were prepared according to five species of wood and two types of grain angle (5x2x10), with ten samples for each parameter. Afterwards, when the moisture content of test samples reached an average of 12%, the specimens were cut to the dimensions of the 20x50x100 mm.

Execution of the Test

A quick thermal conductivity meter based on ASTM C 1113–99, the hot-wire method, was used. A variac (power supply; QTM 500 meter; Kyoto Electronics Manufacturing, Tokyo, Japan) was used to supply constant electrical current to the resistance. The measurement range is 6W/mK. Measurement precision was 5% of the reading value per the reference plate. Reproducibility was given as 3% of reading value. Measurement temperature was within the range 100 to 1000 ºC (external bath or electric furnace for temperature other than room).

Measuring time was standard, 100 to 120 s. During the test operation, the temperature of the hot wire rises rapidly, and this temperature rise spreads outward in the samples. The dimensions of specimens should be large enough so that the temperature on the outer surface of the sample specimen can remain constant during the measurement of the thermal conductivity.

Data Analyses

Data for each test were statistically analyzed by SPSS. The analysis of variance (ANOVA) was used to test for significant difference between factors and levels. When the ANOVA indicated a significant difference among factors and levels, a comparison of means was done employing a Duncan test.

RESULTS AND DISCUSSION

The air dry density of Scots pine, Uludag fir, Oriental beech, Oak, and Chestnut of Anatolia samples were found as 0.47, 0.45, 0.60, 0.80, and 0.52 g/cm^3, respectively. The average values of thermal conductivity determined from the test samples are given in Table 1.

Table 1. Average Values of Thermal Conductivity with Respect to Direction of Grain Angle

Types of wood	Direction of grain angle	Average value (Kcal/mh°C)	Std. Dev.
Beech	Parallel	0.3314	0.081
	Perpendicular	0.2035	0.041
Oak	Parallel	0.2248	0.048
	Perpendicular	0.2222	0.052
Fir	Parallel	0.2105	0.014
	Perpendicular	0.1680	0.043
Scots pine	Parallel	0.1573	0.034
	Perpendicular	0.1563	0.025
Chestnut	Parallel	0.1871	0.029
	Perpendicular	0.1681	0.043

The highest thermal conductivity value was obtained from Oriental beech samples as 0.3314 Kcal/mh°C, in the direction parallel to the grain angle. The lowest value was obtained from Scots pine as 0.1563 Kcal/mh°C, in the direction perpendicular to the grain angle. Thermal conductivity value of samples could have been affected by anatomical structure and chemical characteristics of wood. The variance analyses, as applied on data belong to thermal conductivity determined experimentally, is shown in Table 2.

Örs and Senel (1999) reported that the thermal conductivity values of poplar, cedrus, oriental beech wood, chipboard, and fiberboard were 0.1146, 0.1253, 0.1580, 0.1783, and 0.1998 (Kcal/mh°C), respectively. When taking into account the expected standard deviation of thermal conductivity data, it is found that the present results agree with the literature.

According to the variance analysis, the effects of wood types, direction of the grain angle, and interaction between them were found to be statically significant at the 95% significance level. Comparisons of these means were made by employing a Duncan test to identify which groups were significantly different from other groups, and the results are given in Table 3.

Table 2. Results of Variance Analysis

Source	Degree of freedom	Sum of squares	Mean square	F value	Significant level (P<0.05)
Corrected Model	0.244	9	0.027	13.749	0.000
Intercept	4.117	1	4.117	2091.558	0.000
Factor A	0.151	4	0.038	19.159	0.000
Factor B	0.011	1	0.011	5.711	0.019
A*B	0.081	4	0.020	10.349	0.000
Error	0.177	90	0.002		
Total	4.538	100			
Corrected Total	0.421	99			
Factor A=Wood species (Oriental beech, Oak, Uludağ Fir, Scots pine, Chestnut) Factor B=Grain angle (Perpendicular and Parallel)					

According to the Duncan test results, the thermal conductivity values ranged between 0.1563 and 0.3314 Kcal/mh°C. For instance, thermal conductivity values of Scots pine were found to be very close to each other for the perpendicular and parallel directions with respect to the growth rings (0.1563 to 0.1573 Kcal/mh°C). So, they were assigned to the same homogenous group. The changes of thermal conductivity as grain angle and wood species are shown in Fig. 1.

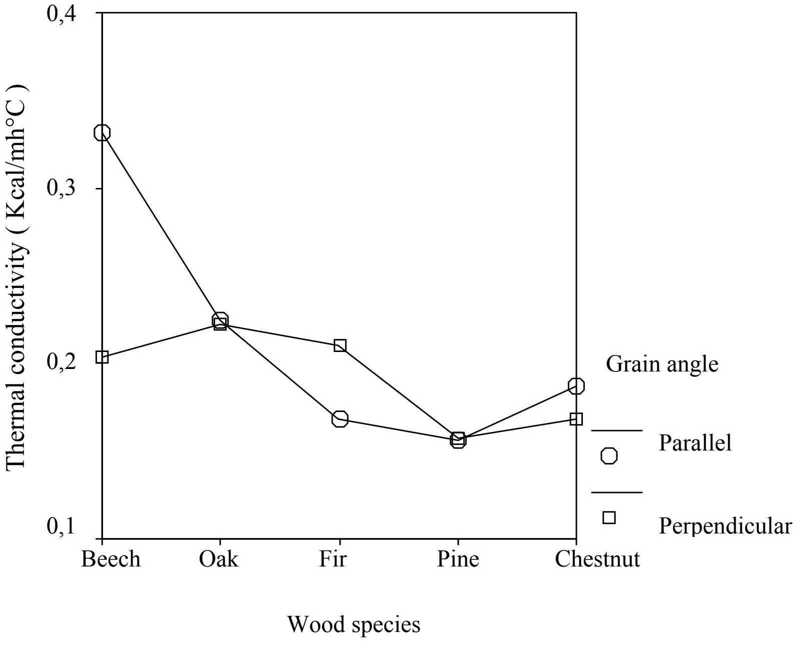

Fig. 1. Thermal conductivity of samples

Table 3. Results of Duncan Test

Properties of test samples	Thermal conductivity (Kcal/mh°C)	Homogenous group
Scots Pine Perpendicular	0. 1563	A
Scots Pine Parallel	0.1573	A
Fir Parallel	0.1680	AB
Chestnut Perpendicular	0.1681	AB
Chestnut Parallel	0.1871	ABC
Beech Perpendicular	0.2035	BC
Fir Perpendicular	0.2105	BC
Oak Perpendicular	0.2222	C
Oak Parallel	0.2248	C
Beech Parallel	0.3314	D

CONCLUSIONS

The thermal properties of wood materials are affected by a number of basic factors such as density, moisture content, extractive content, grain direction, structural irregularities, and temperature. In this study, it was shown that thermal conductivity value of samples could be affected by wood species and grain angle. Thermal conductivity values were found between 0.156 and 0.331 (Kcal/mh°C). While the highest value of thermal conductivity was obtained in Oriental beech, the lowest value of was obtained in perpendicular direction of grain angle, in Scots pine as 0.1563 Kcal/mh°C.

According to data experimental study, thermal conductivity values measured parallel with respect to grain angle were relatively higher than perpendicular direction with respect to the growth rings. It has been said that this difference is very small. In the case of Scots pine there was no significant difference. It was shown that as the density of wood samples increased, the values of thermal conductivity increased. The same time, chemical content and type of extractives materials of wood are very important factors affecting thermal properties.

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