ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 9 N° 4 2013
pp. 679-683

THE TRANSVERSE THERMAL CONDUCTIVITY COEFFICIENTS OF WILD CHERRY WOOD HEAT-TREATED USING THE THERMOWOOD METHOD

Süleyman KORKUT
Department of Forest Industry Engineering, Faculty of Forestry, Duzce University
Address: 81620, Duzce-Turkey
E-mail: suleymankorkut@hotmail.com

Ayhan AYTIN
Program of Furniture and Decoration, Duzce Vocational School, Duzce University
Address: 81100, Duzce-Turkey
E-mail: ayhanaytin@hotmail.com

Çağatay TAŞDEMİR
Department of Natural Resource Ecology and Management, Oklahoma State University
Stillwater, OK-USA
E-mail: tasdemirc9@hotmail.com

Lidia GURĂU
Faculty of Wood Engineering, Transilvania University of Brasov
Address: B-dul Eroilor nr.29, 500036 Brasov-Romania
E-mail: lidiagurau@unitbv.ro

Abstract:

Thermal conductivity values for heat-treated wild cherry (Cerasus avium (L.) Monench) were measured for radial and tangential directions and compared with those for untreated cherry wood. The wild cherry was heat-treated at a temperature of 212°C for two periods of time: 1.5-2.5 hours, respectively. The thermal conductivity test was performed with a quick thermal conductivity meter based on the ASTM C1113-99 (2004) hot-wire method, and measurements were carried out at the room temperature of 20°C. The results show that the heat treatment caused an important decrease on thermal conductivity of wood compared to untreated wood and the thermal conductivity decreased with increasing heat treatment duration. The highest decrease in thermal conductivity was recorded for a treatment duration of 2.5h. Compared with untreated cherry wood, the thermal conductivity on tangential direction, and radial direction of 1.5h and 2.5h heat-treated cherry wood decreased with 22.21%, 19.76% and 29.43%, 29.67% respectively. Radial thermal conductivity was similar to the tangential thermal conductivity. The data are useful when calculating the energy required to kiln-dry lumber and predicting the thermal insulating qualities of log homes made from the species.

Key words: *wild cherry; cerasus avium; thermal conductivity; tangential direction; radial direction.*

INTRODUCTION

Wood is an anisotropic material, whose thermal conductivity is a function of heating direction, temperature, density and moisture. Thermal properties of wood are needed in applications such as fuel conversion, building construction, and other areas of industry (Yapici *et al.* 2011, Hankalin *et al.* 2009). Because of the significant presence of wood and wood products in buildings, the energy design of wood frame buildings and the evaluation of their energy performance depends in part on thermal properties of wood products (TenWolde *et al.* 1988). Information on the thermal conductivity of wood and its relationship to other wood properties is of interest from the standpoint of thermal insulation, drying, plasticizing, preservation, gluing of wood, and where heat resistance of wood is a major consideration in its application (Şahin Kol 2010).

Thermal conductivity is a measure of the rate of heat flow through one unit thickness of a material subject to a temperature gradient. In SI units is expressed in W/mK. In wood, the rate depends on the direction of heat flow with respect to the grain orientation. The thermal conductivity of wood is affected by density, moisture content, extractive content, grain direction, temperature, and structural irregularities such as knots. Thermal conductivity in the radial direction is about equal to thermal conductivity in the tangential direction. But, thermal conductivity parallel to the grain is two to three times what it is radially or tangentially. Wood exhibits low thermal conductivity (high heat-insulating capacity) compared with materials such as metals (aluminum 204.3W/mK, iron 72.7W/mK), marble (2.08 - 2.94W/mK), glass (0.96W/mK), and concrete (1.7W/mK). Thermal conductivity is also influenced by the amount of water in a piece of wood. For wood with moisture content greater than 40%, thermal conductivity is about one to three greater than a piece with moisture content less than 40% (more water, more conductivity). Density influences thermal conductivity. Thermal conductivity is linearly proportional to density, so for denser woods, the thermal conductivity is higher (Samuel *et al.* 2012).

Based on his literature review, Grønli (1996) reports values for effective thermal conductivities for wood at room temperature, parallel with the grain, between 0.158 and 0.419W/mK, and perpendicular to the grain, 0.081–0.209W/mK. Thermal conductivity in the grain direction is 1.5–2.7 times the conductivity perpendicular to the grain direction. Suleiman *et al.* (1999) measured thermal conductivities for Swedish birch of 0.291–0.323W/mK in parallel, and 0.177 – 0.214W/mK perpendicular to the grain direction at room temperature. They observed an increase of 14% in thermal conductivity along the grain and an increase of 24% perpendicular to the grain, on average, as the temperature increased from room temperature to 373K. Based on experiments on 10 Mexican softwoods, Leon *et al.* (2000) derived thermal conductivities of 0.156 – 0.278W/mK for grain direction, 0.112–0.176W/mK for radial direction and 0.074 – 0.133W/mK for tangential direction at room temperature. They concluded that thermal conductivity along the grains is 2.16 times greater than the conductivity in a tangential direction and 1.36 times greater than in a radial direction.

Gupta *et al.* (2003) conducted thermal conductivity tests for a North American softwood with a Fitch type device. They measured 0.0986W/mK perpendicular to the softwood grains, and 0.2050W/mK for the softwood bark. They conclude that the thermal conductivities of the wood and the bark increase linearly by 13% as the temperature increases from 310 to 341K.

A systematic investigation of the variation in the hygrothermal properties of several wood-based building products investigated by (Kumaran *et al.* 2003) revealed a new information on the variations of thermal conductivity, water vapour permeability, moisture diffusivity, water absorption coefficient and air permeability of some classes of wood products. As building materials evolve, there is a need for continuous updating of the information on various thermal properties of wood products (Samuel *et al.* 2012).

This article summarizes the results of thermal conductivity coefficients obtained for wild cherry (*Cerasus avium* (L.) Monench) naturally grown and intensively used for industrial applications in western Turkey. The effects of some parameters (e.g., heat treatment, and grain direction) on thermal conductivity are discussed. To our knowledge, no detailed information is available regarding the thermal conductivity of this species. This article discusses the influence of grain direction on the thermal conductivity in the radial and tangential directions because of their importance in the wood drying process. In addition, for practical building applications, the heat flow is primarily across the grain. The data about the wood species are useful for calculating the energy used during kiln-drying and for estimating the thermal insulating properties of log homes produced from this wood species. The data also allows comparison of the thermal conductivity values of cherry wood with other wood species.

Materials and Methods

The hardwood selected for thermal conductivity measurements was wild cherry. The main criterion for this selection was the commercial importance of this timber in the Turkish market and other factors that relate to the wood itself, such as density and anatomical features.

The sample trees used for the present study were harvested from a mixed oak-hornbeam-wild cherry stand in the Duzce Forest Enterprises, northwestern part of Turkey. From wild cherry species, one tree having approximately 35cm breast height in diameters ([d.sub.1.30]) were used to prepare test samples. To avoid errors during sampling, extreme cases were taken into account, such as excessively knotty trees and those containing reaction wood or slope grain. Sections with a length of 1.5m were cut between 2 and 4m of tree height to obtain samples for thermal conductivity.

Heat treatment was carried out under accurate conditions under steam with a laboratory kiln from Nova ThermoWood in Gerede, Turkey. Steam is used during the drying and heat treatment as a protective vapor. Protective gas prevents the wood from burning and also affects the chemical changes taking place in wood. The heat treatment was applied according to the method described in the Finnish ThermoWood Handbook (Anonymous 2003). At first, the temperature of the kiln was raised near to 1000C. When the temperature inside the wood had risen to near the same temperature, the raising of the kiln temperature was carefully continued to the actual treating temperature. The target temperature was 212^0C. The time of thermal modification at the target temperatures were 1.5 and 2.5h in every test run. After the heat-treatment phase, the temperature was lowered to 80 to 90^0C using water spray system. Conditioning was carried out to moisten the heat-treated wood and bring its moisture content to 5%.

The test samples were obtained from the sapwood region of the 2 m sections. The test samples were prepared by planning the surfaces and sawing into a rectangular shape of 20 by 50 by 100mm according to the procedure of ASTM C177/C518 (2004). To determine the thermal conductivity values at moisture content, ranging approximately 5 percent, samples were prepared in tangential and radial directions. Before testing, each sample was checked on a tabletop to assess flatness, a factor that preliminary testing indicated was critical to consistent thermal conductivity values (Rice and Shepard 2004).

Thermal conductivity measurements were made using a QTM 500 device (Kyoto Electronics Manufacturing, Japan) (Figure 1). The quick thermal conductivity meter based on the ASTM C1113-99 (2004) hot-wire method was used. Variac (power supply) was used to supply constant electrical current to the resistance. A PD-11 box probe sensor (constantan heater wire and chromel-alumel thermocouple) was used. Measurement range was 0.0116 to 6 W/mK. Measurement precision was 5 percent of reading value per reference plate. Reproducibility was 3 percent of reading value per reference plate. The measurement range of the instrument has covered temperatures from -100^0C to 1.000^0C (external bath or electric furnace for temperature other than room). Required sample size was 20 by 50 by 100 mm. Measuring time was standard (100 to 120 s) (Şahin Kol and Sefil 2011).

Fig. 1
Quick Thermal Conductivity-500 type device used for thermal conductivity measurements at Karabük University.

Each sample was tested twice. After each test, each sample was flipped 180 degrees, and the thermal conductivity was retested. Variations in values (>5%) in the readings between each side indicated that samples were warped or defective, and these samples were discarded. The reported data are the averages of the two measurements, although little change was found between the two measurements.

Results and Discussion

Table 1 show the variation of the thermal conductivities with time for the wild cherry wood samples, heat-treated and untreated.

Table 1

Thermal conductivity coefficients of heat-treated and untreated wild cherry wood on radial and tangential directions [a]

Heat Treatment	Times	Unit	Thermal conductivity coefficients (W/mK)	
			Tangential direction (k_T)	Radial direction (k_R)
Control		Avg.	0.1427	0.1433
		± s	0.0037	0.0026
212 °C	1.5 hr.	Avg.	0.111	0.115
		± s	0.004	0.003
	2.5 hr.	Avg.	0.1007	0.1008
		± s	0.002	0.0036

[a] Data collected at 20°C , number of samples measured (n) was 5.
Avg. = average; ±s = standard deviation.

The results show that heat treatment caused an important decrease on thermal conductivity of wood with increasing heat treatment duration under the conditions used. The highest decrease in thermal conductivity was recorded at 212°C for 2.5h. Compared with untreated cherry wood, the heat-treated wood for time spans of 1.5 and 2.5h indicated a decrease in thermal conductivity on tangential and radial directions. with 22.21%, 19.76% and 29.43%, 29.67% respectively. Radial thermal conductivity showed similar values to those on the tangential direction, negligibly higher (Fig. 2).

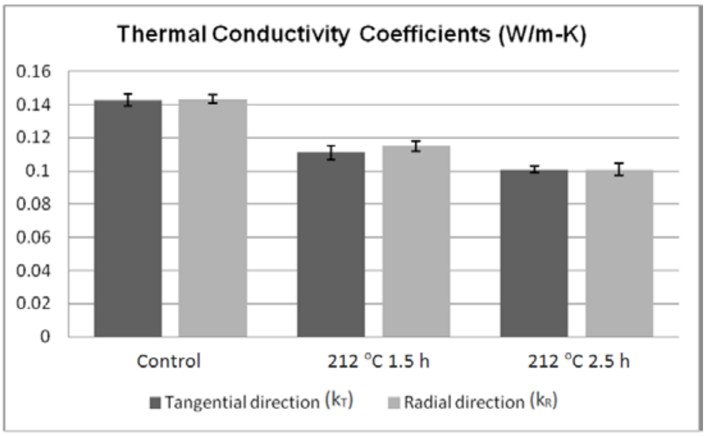

Fig. 2
Graphical illustration of thermal conductivity coefficients of wild cherry wood at structural directions.

The measured thermal conductivity values (Table 1) confirm that thermal conductivity is related to fibre direction.This same trend has been observed in many studies in the literature (Şahin Kol 2009) for the variation of thermal conductivity with fibre direction.

According to Samuel *et al.* 2012, the thermal properties of wood vary with species type with conductivity values generally in the range of 0.1-0.8W/mK. The thermal conductivities values for the samples were found to conform with the general range of conductivity for wood materials.

Yapici *et al.* 2011 found that the lowest thermal conductivity was obtained in the perpendicular direction of Scots pine (*Pinus sylvestris* L.) samples as 0.181W/mK. The highest thermal conductivity was obtained from perpendicular direction of samples in Oriental beech (*Fagus orientalis* L.) as 0.384W/mK.

Vay *et al.* (2013) found that in the cross section, the thermal conductivity of the secondary cell wall was essentially higher than that of the compound middle lamella (CML). In sections parallel to the cell axis, the overall conductivity of the S1 layer was lower than that of the secondary cell wall, but the S2 layer and the CML showed similar conductivities.

Thermal conductivity is a critical attribute when offering energy conserving building products. This is due to the fact that wood has excellent heat insulation properties. Lower thermal conductivity values equates to greater heat insulating properties (Daniel 2010).

CONCLUSION

Thermal conductivity coefficients of the cherry wood species were determined for radial and tangential directions for heat-treated wood at a target temperature of 212^{o}C for 1.5 and 2.5 hour period of time. The highest decrease in thermal conductivity was recorded at 212°C for 2.5h. Radial thermal conductivity was similar to tangential thermal conductivity.

The thermal conductivities values for the samples were found to conform with the general range of conductivity for wood materials. Thermal conductivity is regarded as the most important characteristic of a thermal insulator since it affects directly the resistance to transmission of heat that a material offers. The lower the thermal conductivity value, the lower the overall heat transfer.

ACKNOWLEDGEMENTS

The authors would like to thank Hamiyet Şahin Kol for her experimental assistance.

REFERENCES

Anonymous (2003) ThermoWood Handbook,Finnish ThermoWood Association, Helsinki-Finland

ASTM C1113-99 (2004) Standard test method for thermal conductivity of refractories by hot wire (platinum resistance thermometer technique

ASTM C177/C518 (2004) Methods of measuring thermal conductivity, absolute and reference method

Daniel DP (2010) Perfect Wood Win-Door Profiles, Trace Laboratories, INC 5 North Park Drive Hunt Valley, MD 21030, USA. Pp. 1-5

Grønli MG (1996) Theoretical and experimental study of the thermal degradation of biomass. Doctoral dissertation. Trondheim. Norwegian University on Science and Technology, Faculty of Mechanical Engineering, Dept. of Thermal Energy and Hydropower. Norway, pp. 339

Gupta M, Yang J, Roy C (2003) Specific heat and thermal conductivity of softwood bark and softwood char particles. *Fuel*. Vol. 82:919–927

Hankalin V, Ahonen T, Raiko R (2009) On Thermal Properties of a Pyrolysing Wood Particle, Finnish - Swedish Flame Days 2009, January 28-29, 2009, Naantali - Finland

Kumaran MK, Lackey JC, Normandin N, Tariku F, Reenen DV (2003) Variation in the hygrothermal properties of several wood based building products, Research in Building Physics, Leuven Belgium, pp. 35-42

Leon G, Cruz-de-Leon J, Villasenor L (2000) Thermal characterization of pine wood by photoacoustic and photothermal techniques. *Holz als Roh- und Werkstoff*. 58:24 1-246

Rice RW, Shepard R (2004) The thermal conductivity of plantation grown white pine (*Pinus strobus*) and Red Pine (*Pinus resinosa*) at two moisture content levels, *Forest Products Journal,* 54(1):92-94

Samuel OS, Ramon BO, Johnson YO (2012) Thermal Conductivity of Three Different Wood Products of Combretaceae Family; *Terminalia superb, Terminalia ivorensis and Quisqualis indica*, Journal of Natural Sciences Research, 2(4):36-43

Suleiman BM, Larfeldt J, Leckner B, Gustavsson M (1999) Thermal conductivity and diffusivity of wood. *Wood Science and Technology*. 33:465-473

Şahin Kol H (2009) The transverse thermal conductivity coefficients of some hardwood species grown in Turkey, Forest Products Journal, 59(10):60-64

Şahin Kol H, Uysal B, Kurt Ş, Ozcan C (2010) Thermal conductivity of oak impregnated with some chemicals and finished BioResources 5(2):545-555

Şahin Kol H, Sefil Y (2011) The thermal conductivity of fir and beech wood heat treated at 170, 180, 190, 200, and 212°C, Journal of Applied Polymer Science, 121(4):2473–2480

TenWolde A, McNatt JD, Krahn L (1988) Thermal Properiıes of Wood and Wood Panel Products for Use in Buildings, Forest Products Laboratory, Subcontract Number DE-AI05-870R21697

Vay O, Obersriebnig M, Müller U, Konnerth J, Gindl-Altmutter W (2013) Studying thermal conductivity of wood at cell wall level by scanning thermal microscopy (SThM), Holzforschung 67(2):155–159

Yapici F, Ozcifci A, Esen R, Kurt S (2011) The effect of grain angle and species on thermal conductivity of some selected wood species, BioResources 6(3):2757-2762