# The Thermal Conductivity of Fir and Beech Wood Heat Treated at 170, 180, 190, 200, and 212°C

**Hamiyet Şahin Kol, Yusuf Sefil**

*Furniture and Decoration Department, Karabük University, Technical Education Faculty,*
*Karabük 78050, Turkey*

Received 9 February 2010; accepted 23 November 2010
DOI 10.1002/app.33885

**ABSTRACT:** Heat treatment changes the chemical, physical, and mechanical properties of wood. The properties of heat-treated wood have been researched considerably, but the thermal conductivity of heat-treated wood in various conditions has not been reported. In this study, the thermal conductivity of heat-treated fir and beech wood at temperatures 170, 180, 190, and 212°C for 2 h with ThermoWood method were investigated. The results were compared with industrially kiln-dried reference samples. The results show that heat treatment caused an important reduction on thermal conductivity of wood, the extend of which is depend upon temperature and wood species. Considering all heat treating temperatures, generally by increasing heat treatment temperature the thermal conductivity of wood decreased. The effect of heat treating temperature on thermal conductivity was identical for fir and beech wood. The highest decrease in thermal conductivity occurred at 212°C for both wood species. When compared with untreated wood, the decreases in thermal conductivity at 170°C, and 212°C for fir and beech wood were 2%, 9 and 2%, 16% respectively. Depending on heat treatment temperature, the decrease found out beech in high temperature is higher than that of fir. © 2011 Wiley Periodicals, Inc. J Appl Polym Sci 121: 2473–2480, 2011

**Key words:** thermal properties; modification; heterogeneous polymer; heat treatment; wood

## INTRODUCTION

In the last two decades, many methods have been tried to improve the dimensional stability and durability of wooden material without using chemicals that are harmful to human and the environment. One of these methods, the ThermoWood is based on heating the wood material for a few hours at high temperatures above 180°C under normal pressure while protecting it with water vapor.[1]

It is well known that thermal modification at high temperatures (above 170°C) leads to chemical changes of the wood constituents (polyoses, cellulose, and lignin); this has been subject in numerous publications.[2–6] As a consequence of chemical changes in wood's structure the physical properties of wood are also modified. Dimensional stability are enhanced,[7–9] equilibrium moisture content is lowered,[9–10] color darkens,[11–13] and biological durability is increased.[1,14,15] The degree and intensity of the modifications during heat treatment depend on the process conditions applied: the process type, the duration and the temperature of the heat treatment, and the nature of the wood itself.[4]

Heat-treated wood has a growing market in outdoor applications like exterior cladding wooden buildings, window and door joinery, garden furniture, and decking. There are also many indoor applications for heat-treated wood such as flooring, paneling, kitchen furnishing and interiors of bathrooms and saunas.[16] The increasing presence of heat-treated wood in buildings and outdoor applications, the evaluation of their energy performance depend in part on the thermal properties of wood products is important.[17] In addition, information on thermal conductivity of wood and its relationship to other wood properties is of interest from stand point wood thermal degradation and other processes in which wood is subject to a temperature change.[18–20]

Thermal conductivity of a material can be defined as the rate of heat transfer through a unit thickness of the material per unit area per unit temperature difference. The thermal conductivity of a material is a measure of how fast heat will flow in that material. A large value of a thermal conductivity indicates that the material is a good heat conductor, and a low value indicates that the material is a poor heat conductor or insulator. In solids, heat conduction is due to two effects: the lattice vibrational waves induced by the vibrational motions of the molecules positioned at relatively fixed positions in a periodic

---

*Correspondence to:* H. Ş. Kol (hamiyet_s@hotmail.com or hsahinkol@karabuk.edu.tr).

manner called a lattice, and the energy transported via the free flow of electrons in the solid. In the case of conducting materials, the ability of a material to conduct heat depends on the electrons moving. Thus the contribution of phonons (molecular vibrations) can be neglected in this case.[21,22] In an insulating material, such as wood, 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.[19]

The thermal conductivities of solid wood and wood-based materials have been widely investigated. Previous studies reported that the thermal conductivity of wood varies with the direction of heat flow with respect to the grain, specific gravity, defects, and extractives. The thermal conductivity of wood increases with density moisture content and temperature.[20,23–28] Also, many early studies show that heat-treatment increases the thermal insulation of wood.[9,29–31] However, research regarding thermal conductivity values of heat-treated wood and the changes in the property depending on the heat-treatment temperature has not been reported in details.

Wood is a complex heterogeneous polymer composed of cellulose, hemicellulose, and lignin. During heat treatment, a large chemical changes occur, including the degradation of the hemicelluloses components of wood. As a consequence of chemical changes in wood's structure, the physical properties of wood are also modified. Changes in the chemical, physical, and structural properties of wood after heat treatment can affect the thermal properties of wood. Heat treatment caused reduction of equilibrium moisture content (EMC) of wood.[13,32,33] The decrease in EMC has been related to a decrease in the number of hydrophilic sites in wood, especially hydroxyl groups of carbohydrates. With the degrading of carbohydrates after heat treatment, the concentrations of water-absorbing hydroxyl groups decreases resulting in slow water uptake and absorption.[34] The decreased EMC of heat-treated wood may decrease thermal conductivity of wood. Also, another expected result during heat treatment is the reduction of density.[32,35] In general, as the heat treating temperature rises, the density decreases which can decrease the thermal conductivity of wood.

Fir and beech are the main wood species for industrial-scale heat treatment in Turkey. The goal of this research is to determine how heat treatment affects the thermal conductivity of fir and beech wood. The effect of heat treatment temperature on thermal conductivity has also been examined. The thermal conductivity of heat-treated wood was compared with that of industrial kiln-dried reference samples. The data about the thermal conductivity of heat-treated wood are useful for calculating the thermal insulating value of heat-treated wood material when used indoor and outdoor applications such as cladding wooden buildings, flooring, paneling, kitchen furnishing, interiors of bathrooms and saunas, windows, door joineries, garden furniture, and other processes in which heat-treated wood is subjected to temperature changes.

## EXPERIMENTAL

### Wood species

The data used in this study have been collected within a larger project to assess the physical and mechanical properties of heat-treated Fir (*Abies bornmülleriana Mattf.*) and Oriental beech (*Fagus orientalis L.*). The main criterion for this selection was the commercial importance of the timbers in the Turkish market and other factors that related to the wood itself such as their density and anatomical features. The sample trees used for the present study were obtained from the Bolu Forestry Departments. From two species, five trees having ~ 35–50 cm breast height diameters ($d_{1.30}$) were selected. With the aim of avoiding from errors during sampling, extreme cases were taken into account such as excessively knotty trees and containing reaction wood or slope grain. Sections with 2 m length were cut between 1.30 and 3.30 m height of trees to obtain samples for tests.

The planks chosen for experiments from each wood species were cut from the sapwood region of the sections with 2 m length and planed on four sides to form a cross section of $25 \times 140$ mm$^2$. Prior to heat treatment process, the material was dried using a conventional warm air kiln drying approximately at a temperature of 70°C to a moisture content of 11–15%. The second selection of the raw material was performed at this stage. The density and moisture content of the planks, conditioned at room temperature and relative humidity (RH), were measured and 20 planks with a small variation in density from each species were selected for further experiments. Then these 2 m long planks were split from the middle and cut into five 40 cm long pieces and the other halves of these 20 test planks were left as a reference material (later also called untreated control which was dried at conventional warm air kiln drying temperature of 70°C) and the other halves were heat-treated under steam at five different temperatures according to Figure 1. Thus, the kiln-dried materials were divided into six subgroups, five of which were to be heat-treated under steam at five different temperatures (later also called treated samples) and one of which was left untreated (later also called untreated control).

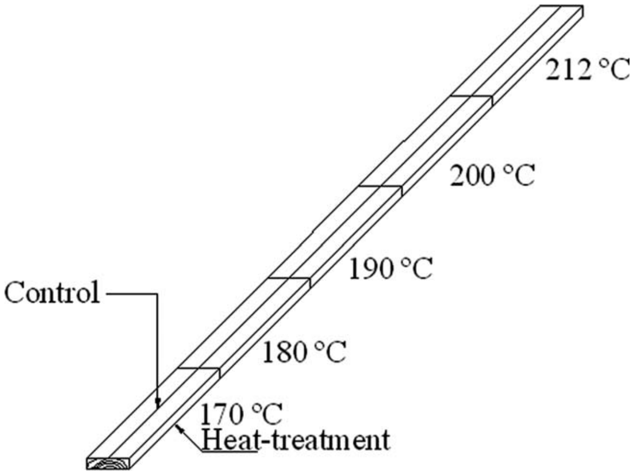

**Figure 1** Descriptions of the wood materials used in tests.

### Heat treatment

Kiln-dried planks (25 mm thickness, 70 mm width, and 400 mm long) were subject to heat treatment using various schedules. 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. According to desired end-use of the material, the heating temperature can vary between 170°C and 215°C with treatment time 2–3 h. The heat treatment was applied according to the method described in the Finnish ThermoWood Handbook.[36] At first, the temperature of the kiln was raised near to 100°C. 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 temperatures were 170, 180, 190, 200, and 212°C. The time of thermal modification at the target temperature was 2 h in every test run. After the heat-treatment phase, the temperature was lowered to 80 to 90°C using water spray system. Conditioning was carried out to moisten the heat-treated wood and bring its moisture content to 4–7%. After heat treatment, only the planks that were free of defects were selected for further testing.

### Determination of the degree of thermal modification

The weight loss caused by the heat treatment was determined. The planks, conditioned to a constant mass, were weighed before and after the heat treatment. Also, the moisture content was measured before and after the heat treatment from small samples taken from the planks. The moisture contents before and after the treatment were reduced to determine the calculated values of the dry weights of the planks.[30]

Weight loss (%), WL, was calculated according to eq. (1).

$$\mathrm{WL} = \frac{(W_{\mathrm{ut}} - W_t) \times 100}{W_{\mathrm{ut}}} \tag{1}$$

where $W_{\mathrm{ut}}$ is the dry weight of the sample before the heat treatment (g) and $W_t$ is the dry weight of the sample after the heat-treatment (g).

Dry weight (g), $W_{\mathrm{dry}}$, was calculated according to eq. (2).

$$W_{\mathrm{dry}} = \frac{100 \times W_u}{u + 100}, \tag{2}$$

where $W_u$ is the weight of the sample at moisture content $u$ (g) and $u$ is the moisture content of the sample (%).

Moisture content (%), $u$, was calculated according to eq. (3).

$$u = \frac{(W_u - W_{\mathrm{dry}}) \times 100}{W_{\mathrm{dry}}}, \tag{3}$$

where $W_u$ is the weight of the sample at moisture content $u$ (g) and $W_{\mathrm{dry}}$ is the dry weight of the sample (g).

### Thermal conductivity tests

To determine the thermal conductivity values at different heat-treatment temperature, samples prepared in tangential and radial directions. The samples with dimensions of 20 × 50 × 100 mm$^3$ were cut from heat-treated and untreated planks according to the procedure of ASTM C 177/C 518.[37] Treated and untreated samples were conditioned in a climate controlled room at 65% RH and 20°C for 6 weeks. Five samples were used in each variation. There were five different heat treating temperatures (170, 180, 190, 200, 212°C) and control untreated samples and two wood species, therefore the total amount of sample was $5 \times 6 \times 2 = 60$.

Thermal conductivity measurements were made using QTM 500 device which is a product of Kyoto Electronics Manufacturing, Japan. The quick thermal conductivity meter based on ASTM C 1113-99[38] hot-wire method was used. Variac (power supply) was used to supply constant electrical current to the resistance. PD-11 box probe sensor (constantan heater wire and chromel-alumel thermocouple) was used. Measurement range is 0.0116–6 W/m-K. Measurement precision is 5% of reading value per reference plate. Reproducibility is 3% of reading value per reference plate. Measurement temperature is $-100°C$ to $1000°C$ (external bath or electric furnace for temperature other than room). Sample size required is $20 \times 50 \times 100$ mm$^3$. Measuring time is standard 100–120 s.

The measurements were made at 20–24°C room temperature. By regular control of the weight, the samples that had already reached their equilibrium moisture content were selected. Each sample was checked on a table-top to assess flatness prior to testing; a factor that preliminary testing indicated was critical to consistent thermal conductivity values.[39] The flat samples were measured and weighed for density calculation. Then the measurements were carried out. Each sample was tested twice. After each test, each sample was reweighed and flipped 180 degrees and the thermal conductivity retested. Variations in values (>5%) in the readings between each side indicated that samples warped or defective and they are discarded.

The air dry densities ($\delta_u$) of the test samples were determined according to TS 2472.[40] The air-dry densities of the samples were calculated according to eq. (4):

$$\delta_u(\mathrm{kg/m^3}) = W_u/V_u \tag{4}$$

where $W_u$ is the air-dry weight (kg) and $V_u$ is the volume (m$^3$) at air-dry conditions.

### Data analyses

Multianalyses of variance were used to determine the differences between the thermal conductivity of the prepared samples and a simple comparison of the means was done employing Duncan's test to identify which groups were significantly different.

## RESULTS AND DISCUSSION

The weight losses, moisture content, and densities (weight and volume determined from samples conditioned at RH 65% and 20°C) of the samples used in the tests are presented in Table I. The results showed that the heat treatment resulted in weight loss of the wood materials (Table I) and the higher the heat treatment temperature, the greater the weight loss. The weight loss of beech was higher than fir wood. Hardwoods are less thermally stable than softwoods and this is attributable to differences in the hemicullulosic content and composition. Pentosans (which are found in higher proportions in hardwood hemicelluloses) are more susceptible to thermal degradation than hexosans.[41] Weight loss is an indicator of the changes in wood. In general higher weight losses indicates better antiswelling efficacy. Also the density and moisture content of samples decreased by the heat treatment (Table I). By increasing heat treatment temperature the decrease in density of the specimens was inconsiderable while the decrease in the moisture content was significant and the higher the heat treatment temperature, the lower the moisture content. The effect of heat treating temperature on moisture content was identical for fir and beech wood. Similar results were obtained by Gunduz and Aydemir,[13] Kaygın et al.,[33] Gunduz et al.,[32] Vital and Lucia.[35] Mainly chemical alteration of thermal instable polyoses causes property change of wood in terms of moisture uptake and density. Vital and Lucia[35] stated that the primary reason for the density reduction was the degradation of hemicelluloses, which are less resistant to heat than cellulose and lignin. Burmester[42] and Tjeerdsma and Militz[2] explained that reduction of free accessible hydroxyl groups results in decreased moisture uptake. Additionally, Tjeerdsma et al.[43] stated that hydrophopic substances are formed due to crosslinkage reactions of the wood polymers.

**TABLE I**
**Moisture Content, Densities, and Weight Loss of the Samples**

| Wood Species | Modification temperature (°C) | Moisture content (%) | Density (kg/m$^3$) | Weight loss (%) |
|---|---|---|---|---|
| Fir | Untreated | 10.3 (0.53) | 457 (0.027) | 0.0 |
| | 170 | 6.8 (0.86) | 448 (0.019) | 1.7 (0.20) |
| | 180 | 6.4 (0.61) | 434 (0.015) | 1.8 (0.20) |
| | 190 | 5.9 (0.88) | 421 (0.035) | 2.5 (0.19) |
| | 200 | 4.8 (0.70) | 412 (0.027) | 2.8 (0.20) |
| | 212 | 3.7 (0.89) | 404 (0.033) | 5.4 (0.19) |
| Beech | Untreated | 9.6 (0.74) | 641 (0.035) | 0.0 |
| | 170 | 6.2 (0.59) | 635 (0.037) | 1.2 (0.14) |
| | 180 | 5.3 (0.68) | 625 (0.037) | 2.6 (0.13) |
| | 190 | 4.3 (0.55) | 616 (0.039) | 3.3 (0.14) |
| | 200 | 3.5 (0.75) | 609 (0.025) | 3.9 (0.14) |
| | 212 | 3.4 (0.66) | 595 (0.029) | 7.3 (0.15) |

Results are means (standard deviations) of five samples.

The average values of thermal conductivity of the untreated and heat-treated specimens at different heat treatment temperatures in tangential and radial directions are given in Table II. By comparing the control (untreated samples) and heat-treated samples in Table II, it can be seen that the heat treatment decreased the thermal conductivity of wood. This result is in agreement with the earlier literature.[9,29–31] For both fir and beech, the highest thermal conductivity was obtained with the samples cut radially and untreated ones and the lowest with the samples cut tangentially and heat treated at 212°C (Table II).

Variance analysis results about the effects of wood species, directions, and heat treatment temperature on thermal conductivity are given in Table III.

**TABLE II**
**The Tangential (*T*) and Radial (*R*) Thermal Conductivity of Woods with Regard to Heat Treatment ($P \leq 0.05$)**

| | | Thermal conductivity coefficients (W/m-K) | |
|---|---|---|---|
| Direction | Process | Fir | Beech |
| *T* | Untreated | 0.1297 (0.001) E | 0.1824 (0.002) E |
| | 170 | 0.1267 (0.001) D | 0.1790 (0.001) D |
| | 180 | 0.1237 (0.003) C | 0.1762 (0.001) D |
| | 190 | 0.1220 (0.001) BC | 0.1718 (0.002) C |
| | 200 | 0.1202 (0.001) AB | 0.1617 (0.004) B |
| | 212 | 0.1192 (0.003) A | 0.1556 (0.001) A |
| | Total | 0.1235 (0.004) | 0.1711 (0.001) |
| *R* | Untreated | 0.1362 (0.002) E | 0.1911 (0.003) F |
| | 170 | 0.1329 (0.002) D | 0.1867 (0.001) E |
| | 180 | 0.1294 (0.001) C | 0.1818 (0.002) D |
| | 190 | 0.1269 (0.002) B | 0.1751 (0.002) C |
| | 200 | 0.1249 (0.003) AB | 0.1625 (0.002) B |
| | 212 | 0.1235 (0.001) A | 0.1564 (0.004) A |
| | Total | 0.1289 (0.005) | 0.1756 (0.013) |

Results are for means, (standard deviation), and letter ranking per Duncan's multiple range test for significance level of 0.05 for the five samples. Differences between mean values with same letter are not significant.

Duncan's multiple comparison tests were used to determine the differences between the treatment groups and the test results are shown in Table II as letters. Statistical analysis showed some noticeable differences ($P < 0.05$) between thermal conductivity mean-values of wood species. The thermal conductivity of beech wood was higher than that of fir wood (Table III). The general trends of density of the wood species are identical to those of the thermal conductivity values of the wood species. The observations confirm the data found in the literature on this subject. It can be claimed that the differentiation of thermal conductivities of wood species found in this study are strongly related to the specific gravity and thermal conductivity increases as specific gravity increases.[24,27,39]

The variance analysis results show that the radial values were somewhat higher than the tangential ones ($P < 0.05$) for both wood species when the whole heat treatment temperatures are taken into consideration (Table III). It can be said that the effect of grain orientation of untreated wood on thermal conductivity is similar that of heat treated wood. The influence of grain orientation on thermal conductivity has been proved by several scientists. Wangaard,[24] Suleiman et al.,[25] and Steinhagen[26] pointed out that radial conductivity may be higher than tangential conductivity and the ratio of the tangential to radial conductivity is primarily determined by the volume of the ray cell in hardwoods. The important result of this research is the thermal conductivity of heat-treated samples is rather lower than that of the untreated samples. Variance analysis results show that process of heat treatment significantly decreased the thermal conductivity of wood ($P < 0.05$; Table III). These results can be explained by considering the combination of two facts. First, heat treatment causes reduction of EMC of wood. It is very remarkable that in this study, the EMC of heat treated wood was absolutely lower than untreated wood (Table I). The decrease in EMC has been related to a decrease in the number of hydrophilic sites in wood, especially hydroxyl groups of carbonhydrates. With the degrading of carbonhydrates after heat treatment, the concentrations of water-absorbing hydroxyl groups decrease resulting in slow water uptake and absorption. Thus the amount of water within the wood matrix decreases. It is known that there is a very strong correlation between moisture content and thermal conductivity value and the thermal conductivity increases with increasing moisture content.[24,27,44,45,46] Because the thermal conductivity of water is many times higher than those of wood, a trend of decreased thermal conductivity of heat-treated wood is expected. Second, heat treatment decreases the density of wood (Table I). The thermal conductivity of wood decreases when the density of wood decreases. It is very remarkable that in this study, the moisture content and density of heat- treated wood samples were absolutely lower than untreated wood samples. Thus, it is expected that the decreased density and moisture content reduced the thermal conductivity of heat-treated wood. Because of these reasons, it

**TABLE III**
**Variance Analysis Results with Regard to the Effects of Wood Species, Direction, and Process on Thermal Conductivity**

| Source | Sum of squares | Degree of freedom | Mean square | *F* ratio | Significance |
|---|---|---|---|---|---|
| Wood species | 0.066 | 1 | 0.066 | 15,985.988 | 0.000 |
| Direction | 0.001 | 1 | 0.001 | 177.043 | 0.000 |
| Process | 0.007 | 5 | 0.001 | 320.712 | 0.000 |
| Wood × direction | 7.272E-6 | 1 | 7.272E-6 | 1.748 | 0.189 |
| Wood × process | 0.002 | 5 | 0.000 | 78.294 | 0.000 |
| Direct × process | 0.000 | 5 | 2.300E-5 | 5.530 | 0.000 |
| Wood × direction × process | 3.978E-5 | 5 | 7.956E-6 | 1.913 | 0.099 |

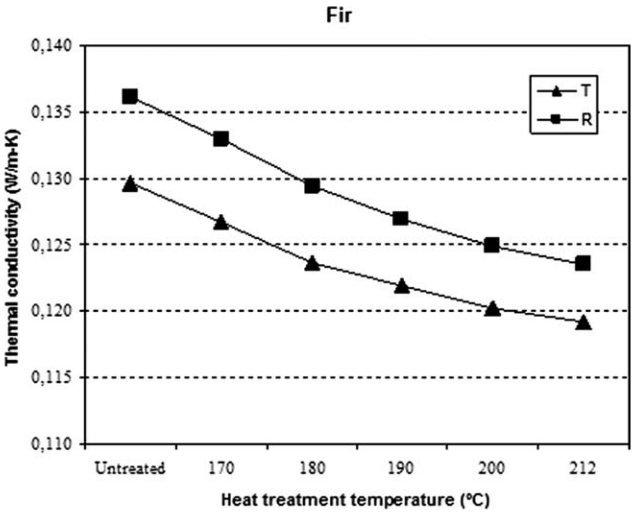

**Figure 2** The effect of heat treatment temperature on the thermal conductivity of fir wood.

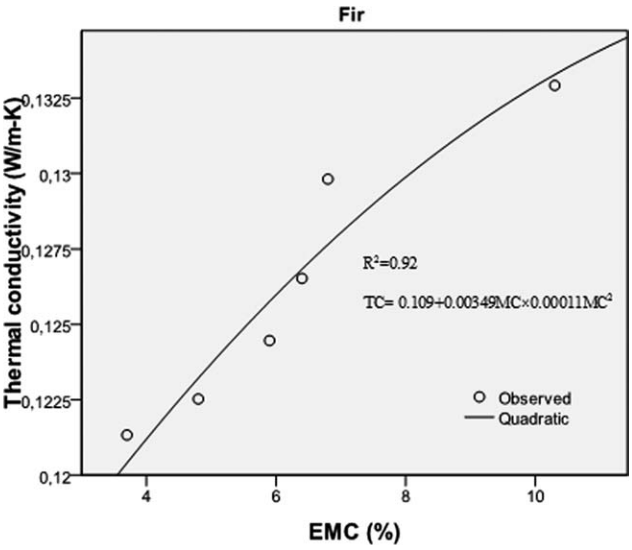

**Figure 4** The relationship thermal conductivity and equilibrium moisture content of heat-treated fir wood.

can be claimed that the differentiation of thermal conductivity of untreated and heat-treated wood in this study are strongly related to the decreased moisture content and density of heat-treated wood.

Statistical analysis (Table III) showed some noticeable differences ($P < 0.05$) between thermal conductivity values of test groups according to heat treatment temperature. Figures 2 and 3 present the changes of thermal conductivity of wood comparing fir and beech wood before and after heat treatment. It appears that there exists a significant difference in thermal conductivity values among heat treating temperature. With increasing heat treating temperature, the values showed a significant decrease. This trend was similar for both wood species studied. Figures 2 and 3 indicate that at the beginning of the temperature load (at 170°C) the thermal conductivity value gradually decreased and after this point the thermal conductivity showed significantly decreases with temperature increase and reached the minimum value at 212°C.

Tests showed that when compared with untreated wood, the thermal conductivity of heat-treated fir at reduces by an average of 2% at 170°C, 5% at 180°C, 6% at 190°C, 8% at 200°C, and 9% at 212°C, respectively. For beech wood, the decreases are by an average of 2, 4, 7, 13, and 16%, respectively. According to the results obtained, the lowest and highest decreases in thermal conductivity occurred for treatment at 170°C and 212°C and when the beech and fir wood species are compared, the decrease found out beech in high temperature is higher than that of fir depending on heat treatment temperature.

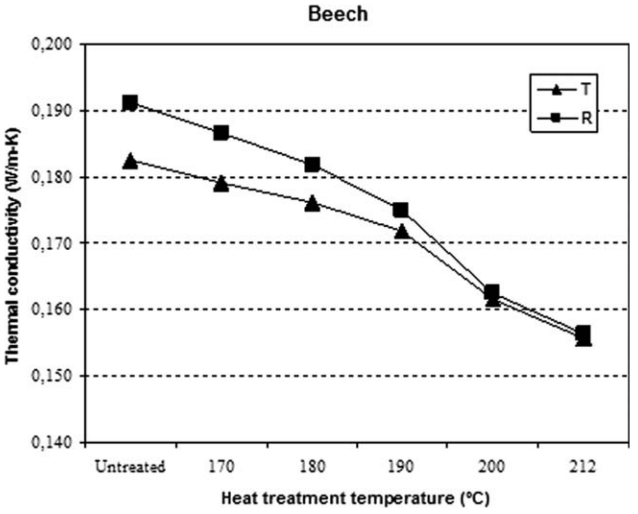

**Figure 3** The effect of heat treatment temperature on the thermal conductivity of beech wood.

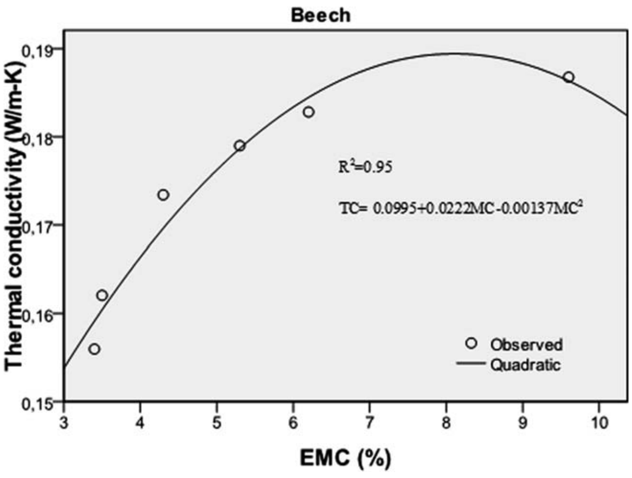

**Figure 5** The relationship thermal conductivity and equilibrium moisture content of heat-treated beech wood.

This is attributable to differences in the chemical composition of wood species. It is known that hardwoods are less thermally stable than softwoods.[41]

The differences in the thermal conductivity of heat-treated woods among heat-treatment temperatures may be related to one or more of specific changes occurred during heat treatment. Among these, decreased equilibrium moisture content and decreased density may be decisive. The data available have permitted the analysis of a relationship between the thermal conductivity and moisture content of heat treated wood. For both wood species, second-order equations provided the best fitted curves for the experimental data for thermal conductivity and moisture content of heat treated wood. Second order equations of the type $Y = ax^2 + bx + c$ were used for curve-fitting the thermal conductivity as a function of EMC for heat-treated wood. Figures 4 and 5 give the relationship between EMC and TC of heat treated. Examining regression coefficients for fir and beech wood were 0.92 and 0.95, respectively. Hence, it can be stated that the general trend of moisture content of heat-treated wood according to heat treatment temperature is absolutely overlap the trend of their of thermal conductivity behavior.

## CONCLUSIONS

The results indicate that the thermal conductivity of all heat-treated samples decreased compared with the control (untreated) samples and the thermal conductivity generally decreases with increasing heat treatment temperature. The thermal conductivity of heat-treated beech wood was higher than that of heat-treated fir wood. The thermal conductivity behavior of fir and beech wood according to heat treating temperature was relatively similar. However, more decrease has been observed on thermal conductivity of beech in high temperature. The lowest and highest decreases in thermal conductivity occurred for treatment at 170°C and 212°C for both wood species. The thermal conductivity of heat treated fir and beech wood at 212°C was reduced by 9 and 16%, when compared with untreated woods.

Because of its good thermal insulation, heat-treated wood is well suited for applications where the insulation is required such as saunas, outer doors, cladding, and windows. The decreases of thermal conductivity according to heat treatment temperature showed that the treatment level could be set to create a product where a specified using area is desired. By taking their using area, physical, and mechanical features into consideration fir and beech wood could be preferred, respectively.

The authors thank to Nova Thermo Wood for using their Laboratory for this study.

## References

1. Viitaniemi, P. Ind Horiz 1997, 23, 77.
2. Tjeerdsma, B. F.; Militz, H. Holz RohWerkst 2005, 63, 102.
3. Windeisen, E.; Strobel, C.; Wegener, G. Wood Sci Technol 2007, 41, 523.
4. Nuopponen, M. FT-IR and UV Raman Spectroscopic Studies on Thermal Modification of Scotch Pine Wood and Its Extractable Compounds; Helsinki University of Technology: Espoo, Finland, 2005.
5. Alén, R.; Kotilainen, R.; Zaman, A. Wood Sci Technol 2002, 36, 163.
6. Boonstra, M. J.; Tjerdsma, B. Holz RohWerkst 2006, 64, 204.
7. Viitaniemi, P. Wood—The Ecological Material. In: Proceedings of the 4th Euro-Wood Symposium; Stockholm, Sweden, 1997. Trätek Rapport No. P9709084.
8. Yıldız, S. In: Proceedings of the Annual Meeting International Research Group on Wood Preservation, Effect of heat treatment on water repellence and anti-swelling efficiency of beech; Wales, UK, 2002. IRG/WP 02–40222.
9. Esteves, B. M.; Domingos, I. J.; Pereira, H. M. BioResources 2007, 3, 142.
10. Jämsä, S.; Viitaniemi, P. In: Proceedings of COST E22 Environmental Optimisation of Wood Protection, Heat treatment of wood. Better Durability without Chemicals; Antibes, France, 2001.
11. Johansson, D.; Morén, T. Holz RohWerkst 2006, 64, 104.
12. Unsal, O.; Korkut, S.; Atik, C. Maderas Cienc Technol 2003, 5, 145.
13. Gunduz, G.; Aydemir, D. Dry Technol 2009, 27, 714.
14. Boonstra, M. J.; Van Acker, J.; Kegel, E.; Stevens, M. Wood Sci Technol 2007, 41, 31.
15. Kandem, D. P.; Pizzi, A.; Jermannaud, A. Holz RohWerkst 2002, 60, 1.
16. Viitaniemi, P. Ind Horiz 2000, 9.
17. Tenwolde, A.; McNatt, J. D.; Krahn, L. Thermal Properties of Wood and Wood Panel Products for Use in Buildings; UDA Forest Service: Madison, WI, 1988.
18. Sanyal, S. N.; Jain, V. K.; Dubey, Y. M.; Verma, P. C. J Ind Acad Wood Sci 1991, 22, 45.
19. Gu, H. M. Structure Based, Two-dimensional Anisotropic, Transient Heat Conduction Model for Wood; Virginia Polytechnic Institute and State University: Blacksburg, VA, 2001.
20. Gu, H. M.; Zink-Sharp, A. Wood Fiber Sci 2005, 37, 699.
21. Simpson, W.; TenWolde, A. Wood Handbook, Wood an Engineering Material, GTR 113; U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: Madison, WI, 2003; Chapter 3.
22. Çengel, Y. A. Heat Transfer: A Practical Approach; McGraw-Hill, New York, 2003.
23. Rowley, F. B. Heat Piping Air Cond 1933, 5, 313.
24. Wangaard, F. F. Heat Piping Air Cond 1940, 12, 459.
25. Suleiman, B. M.; Larfeldt, J.; Leckner, B.; Gustavsson, M. Wood Sci Technol 1999, 33, 465.
26. Steınhagen, H. P. Thermal Conductive Properties of Wood Green or Dry from −40° to +100°C: A Literature Review; USDA Forest Service: Madison, 1977.
27. MacLean, J. D. Heat Piping Air Cond 1941, 13, 380.
28. Sahin Kol, H.; Altun, S. Dry Technol 2009, 27, 1010.
29. Militz, H. In: 33rd Annual Meeting International Research Group Wood Protection, Thermal treatment of wood: European processes and their background; Cardiff-Wales, 2002.
30. Kortelainen, S. M.; Antikainen, T.; Viitainiemi, P. Holz Roh Werkst 2006, 64, 192.
31. Santos, J. A. Wood Sci Technol 2000, 34, 39.
32. Gunduz, G.; Nimemz, P.; Aydemir, D. Dry Technol 2008, 26, 1135.
33. Kaygın, B.; Gunduz, G.; Aydemir, D. Dry Technol 2009, 27, 89.

34. Kartal, S. N.; Hwang, W. J.; Imamura, Y. J Wood Sci 2007, 53, 454.
35. Vital, B. R.; Lucia, M. D. Rev Arvore 1983, 7, 136.
36. Finnish ThermoWood Association. ThermoWood Handbook: Helsinki, 2003.
37. ASTM. Methods of Measuring Thermal Conductivity: Absolute and Reference Method, ASTM C 177/C 518; ASTM: West Conshohocken, USA, 2004.
38. ASTM. Standard Test Method for Thermal Conductivity of Refractories by Hot Wire (Platinum Resistance Thermometer Technique), ASTM C 1113–99; ASTM: West Conshohocken, USA, 2004.
39. Rice, R.W.; Shepard, R. Forest Prod J 2004, 54, 92.
40. Turkish Standard Institution. TS 2472: Wood—Determination of Density for Physical and Mechanical Tests; TSE: Turkey, 1976.
41. Hill, C. A. S. Wood Modification, Chemical, Thermal and Other Processes; Wiley: England, 2006.
42. Burmester, A. Holz RohWerkst 1975, 2, 112.
43. Tjeerdsma, B. F.; Boonstra, M.; Pizzi, A.; Tekely, P.; Militz, H. Holz RohWerkst 1998, 56, 149.
44. Gu, H. M.; Hunt, J. F. Wood Fiber Sci 2007, 39, 159.
45. Kurt, Ş. J Appl Polym Sci 2008, 110, 1822.
46. Kol, H. S. Forest Prod J 2009, 59, 58.