ISSN 0717-3644
ISSN online 0718-221X

THE DENSITY, COMPRESSION STRENGTH AND SURFACE HARDNESS OF HEAT TREATED HORNBEAM (Carpinus betulus) WOOD

Gokhan Gunduz[1], Suleyman Korkut[2], Deniz Aydemir[1], Ílter Bekar[2]

ABSTRACT

The heat treatment of wood is an environment-friendly method for wood preservation. The heat treatment process only uses steam and heat, and no chemicals or agents are applied to the material during the process. Tests have shown no harmful emissions are apparent when working with the material. This process improves wood's resistance to decay and its dimensional stability. In this study, the density, compression strength and hardness of heat treated hornbeam (*Carpinus betulus* L.) wood were investigated. Wood specimens that had been conditioned at 65% relative humidity and 20 ºC were subjected to heat treatment at 170, 190, and 210 ºC for 4, 8, and 12 hrs. After heat treatment, compression strength and hardness were determined according to TS 2595 and TS 2479. The results showed that the decreases of compression strength and hardness were related to the extent of density loss. Both compression strength and hardness decreased with the increasing temperatures and durations of the heat treatment. While the maximum density loss observed was 16.12% at 210 ºC and 12 hour, at these heat-treatment conditions, the compression strength approximately decreased 30% and hardness values in tangential, radial, and longitudinal directions approximately decreased by 55%, 54%, and 38%, respectively. Hence, it was concluded that there might be a relationship between changes of these wood properties.

Keywords: Heat treatment, density, compressive strength, hardness, hornbeam wood, Carpinus betulus L

INTRODUCTION

In recent years, the production of heat-treated wood has increased rapidly (Ewert and Scheiding 2005). Heat treatment has been reported to be an effective method for improving the dimensional stability and the durability of wood (Bourgois *et al.* 1998; Tjeerdsma *et al.* 1998). Several research groups have developed heat-treatment methods that are suitable for industrial applications (Boonstra *et al.* 1998; Viitaniemi *et al.* 1996; Weiland *et al.* 2003).

During the high temperature treatment, the wood species are heated slowly up to 200–230 ºC in humid inert gas. This treatment reduces the hydrophilic behavior of the wood by modifying the chemical structure of some of its components (Raimo *et al.* 1996; Gailliot 1998). This modification prevents the re-absorption of water which promotes wood decay. When wood absorbs humidity from its surroundings, water molecules are inserted between and within the wood polymers (hemicelluloses and amorphous cellulose), and hydrogen bonds are formed. This phenomenon makes the wood swell (Hinterstoisser *et al.* 2003).

[1] Department of Forest Industrial Engineering, Faculty of Forestry, Bartin University, Bartin, Turkey.
[2] Department of Forest Industrial Engineering, Faculty of Forestry, Duzce University, Düzce, Turkey.
Corresponding author: suleymankorkut@duzce.edu.tr
Received: 25.09.2008. Accepted: 13.01. 2009.

After heat treatment wood becomes more rigid and fragile, and the mechanical resistance decreases (Poncsak *et al.* 2006; Sevim Korkut *et al.* 2008; Korkut and Bektas 2008; Korkut *et al.* 2008). Depending on the treatment parameters such as the maximum treatment temperature, the heating rate, the holding time at the maximum temperature or the nitrogen gas humidity, cracks can appear and the cell structure can be partially degraded as well (Poncsak *et al.* 2006; Kocaefe *et al.* 2007). Temperature has a greater effect on many wood properties than does treatment time (Kartal *et al.* 2007). Temperatures over 150 ºC permanently alter the physical and mechanical properties of wood (Mitchell 1998).

Heat treatment significantly reduces the tangential and radial swelling. The desired changes begin to occur at about 150 ºC, and the changes continue as the temperature is increased in stages (Gunduz *et al.* 2007). In another study, Yildiz (2002) used a technique that involved increased temperatures and treatment times, and the results showed changes in dimensional stability ranging from 55% to 90%. Heat treatment decreased the water absorption of Uludag fir (*Abies bornmulleriana* Mattf.). Therefore, the extent to which the equilibrium moisture content of uludag fir is reduced depends strongly on the heat-treatment temperature, namely, the higher the heat-treatment temperature, the lower the level of absorbed moisture and equilibrium moisture content (Aydemir 2007). On the other hand, as a result of heat treatment, the wood becomes more brittle, and its mechanical strength and technological properties decrease in relation to the level of heat treatment (Gunduz *et al.* 2007). In addition, heat treatment results in varying amounts of weight loss, depending on the treatment temperature and exposure time. For Norway spruce (*Picea abies* L.) wood, a 24 – h heat treatment resulted in weight losses of 0.8% and 15.5% at 120 ºC and 200 ºC, respectively. Weight losses of beech (*Fagus sylvatica* L.) wood, treated at 150 ºC and 200 ºC were 8.1% and 9.8%, respectively (Bekhta and Niemz 2003).

Some treatment methods resulted in a strong decrease of the impact strength and bending strength while others did not or in a lower extent. Furthermore, a recent study by Boonstra *et al.* (2007) showed a strong decrease of the tensile strength, much higher than the bending strength. Unsal and Ayrilmis (2005) also found that the maximum decrease of compression strength parallel to the grain in Turkish river red gum (*E. camaldulensis* Dehn.) wood samples was 19%, treated at 180 ºC for 10 hrs. Heat-treated wood can be used for several purposes, e.g., for garden, kitchen, and sauna furniture; for floors and ceilings; to replace bricks on the outside and inside of structures; and for doors and windows (Korkut 2007; Korkut *et al.* 2007).

The aim of this study is to examine the relation between the density and the compression strength and hardness of hornbeam wood. Because the wood used in this study had already been heat treated, this study did not assess the effect of the temperature and duration of heat treatment on density losses in the wood.

MATERIALS AND METHODS

The hornbeam (*Carpinus betulus* L.) wood samples used in this study were obtained in Bartin, Turkey. Two trees with a diameter at breast height diameter (DBH 1.3 m above ground) of 35–40 cm were obtained from Bartin Forest Enterprises. Hornbeam, having superior technological properties and having high usage potential, is an important species in lumber industry. The dimensions of the samples used for density, compression strength, and hardness studies were 20 x 20 x 30 mm, 20 x 20 x 30 mm, and 50 x 50 x 50 mm, respectively (TS 2470). The number of specimens taken from each log was equal. Heat treatment applications were applied at three temperatures (170, 190, and 210 ºC) and three durations (4, 8, and 12 h) in a small heating unit controlled at ±1ºC sensitivity under atmospheric pressure.

Tests for density (air-dry), compression strength, and Brinell hardness were carried out based on TS 2472, TS 2595, and TS 2479, respectively, on the 30 replicates used in the experiment. After compression strength and hardness tests, the moisture content of the samples was measured according to TS 2471, and strength values were corrected based on 12% EMC. Variance analysis was applied in the analysis of the results in this study.

RESULTS AND DISCUSSION

All statistical calculations were based on the 95% confidence level. ANOVA and Tukey's Multiple Range Tests show that all differences were significant (Table 1).

Table 1 shows the influence of heat treatment at different temperatures and durations on compression strength and hardness as compared to control specimens. Heat treatment results indeed in a decrease of density. The decrease of the density is caused by: 1. a lower moisture content, 2. Evaporation of extractives during heat treatment, 3. Degradation of wood components, especially the hemicelluloses, and evaporation of degradation products. The decrease of the mechanical properties is mainly caused by the degradation of wood components (cellulose and especially the hemicelluloses), and this degradation is also a reason why the density is decreased (Boonstra *et al.* 2007)

The extent to which these properties (density, compression strength and hardness) were decreased was determined for all the heat treatment conditions.

Table 1 shows the changes in mechanical properties of heat-treated wood at different temperatures and durations. The data were statistically evaluated by one-way ANOVA to determine the influence of heat treatment on compression strength and hardness.

Differences between heat treatment and control specimens were statistically significant at the 5% confidence level. Also, the effects of density changes of heat-treated hornbeam wood on the wood's compression strength and hardness were investigated. Figure 1 show the compression strength (CS) loss of heat-treated hornbeam wood (a) is 170 ºC, (b) is 190 ºC, and (c) is 210 ºC).

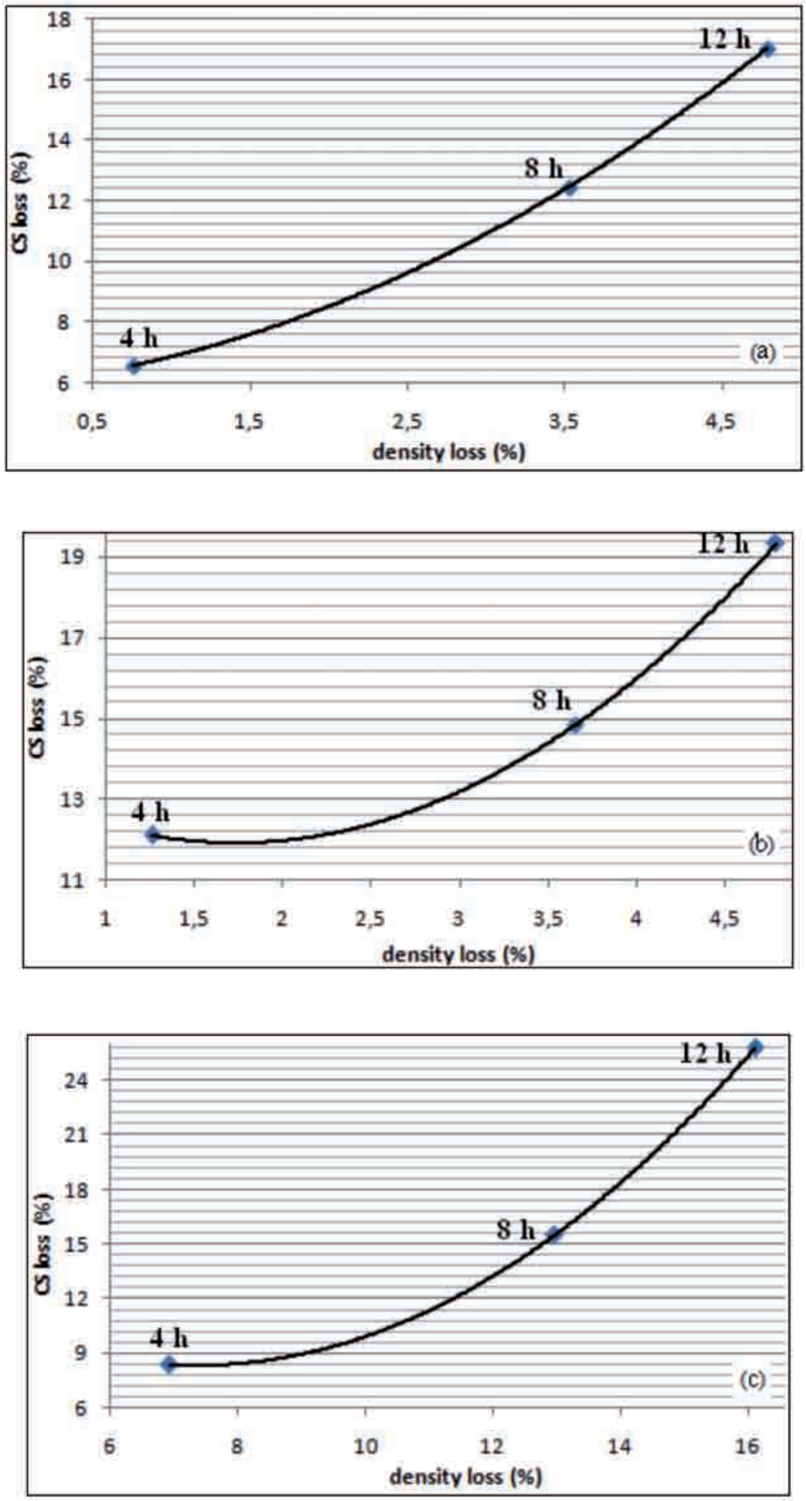

Figure 1. The compression strength changes of heat-treated hornbeam wood ((a) is 170 ºC, (b) is 190 ºC, and (c) is 210 ºC).

According to Figure 1, after heat treatment at 170 ºC for 4 hrs, the compression strength values showed a small decrease. When the treatment times were increased at the same temperature, the decreases in compression strength for wood samples exposed for durations of 4 and 12 hrs were greater than the decreases for wood samples exposed for 8 hrs. Figure 2 shows the relation between compression or hardness and density after heat treatment.

According to Fig. 2, it was determined that density changes have more effects on hardness in different sections than compression strength. This effect increased as treatment temperature and duration was increasing. It was found to be a significant correlation among density, compression strength and hardness in different sections.

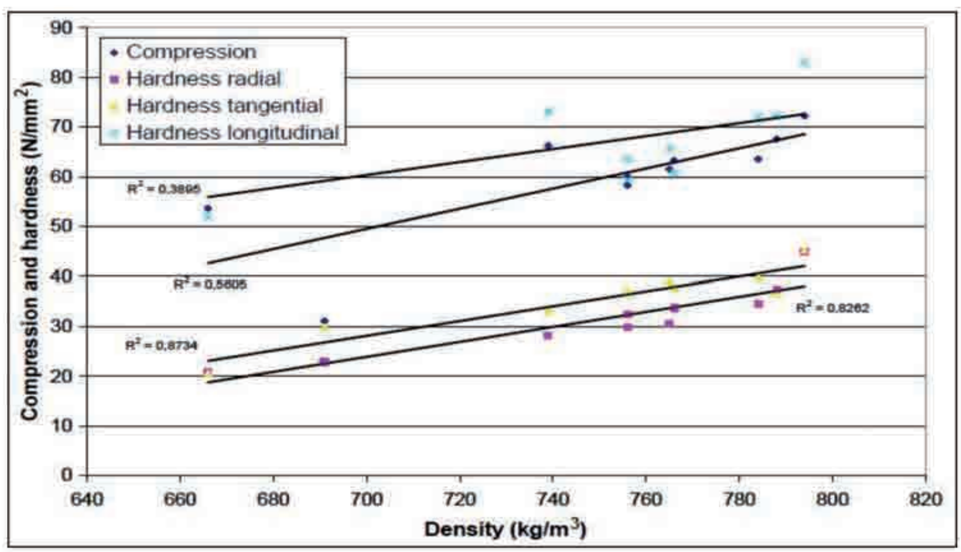

Figure 2. Relation between compression or hardness and density after heat treatment.

When the treatment temperature was 210 ºC, compression strength decreased as expected for exposures of 4 and 8 hrs. However, for an exposure of 12 h at this temperature, compression strength was determined to have decreased more than other treatment conditions. As a result of this study, we determined that heat treatment causes mass losses in the wood, which has a negative effect on density. Thus, the greatest density loss occurred for treatment conditions of 200 ºC and 12 h. The smallest decrease in compression strength was found at treatment conditions of 170 ºC and 4 h, where the compression strength was measured about 68 N/mm^2.

The largest decrease in compression strength occurred at treatment conditions of 210 ºC and 12 h, where the compression strength was measured about 54 N/mm^2. The compression strength losses for 170 ºC and 4 h was 7 %, while for 210 ºC and12 h, it was 34.7%. Korkut *et al.* (2007) obtained similar compression strength results for Scots pine (*Pinus sylvestris* L.) wood for the same treatment times and temperatures. Gunduz *et al.* (2007) reported that the maximum decreases for all parameters were recorded at treatment conditions of 180 ºC and 10 h. The lowest compression strength value obtained was 41.432 N/mm^2, a loss of 27.2% compared to the control.

Unsal and Ayrilmis (2005) also found that the maximum decrease in compression strength parallel to grain in Turkish river red gum (*E. camaldulensis* Dehn.) wood samples was 19.0% at treatment conditions of 180 ºC and 10 h. Several studies showed different effects on the hardness of wood, a decrease but also an increase has been noticed (depending on the wood species and treatment method). We also determined that hardness decreased to varying extents in heat-treated hornbeam wood, depending on the temperature and duration of treatment.

Table 1. The changes in mechanical properties of heat-treated Hornbeam wood at different temperatures and durations.

Temperature (ºC)	Duration (hrs)	Statistical Values	Density (g/cm^3)	Compression Strength (N/mm^2)	Hardness (N/mm^2)		
					Tangential	Radial	Longitudinal
Control	none	*Avg.*	**0.794**	**72.29**	**44.91**	**45.27**	**83.09**
		± s	0.015	0.86	2.102	3.535	3.001
		V	1.845	1.19	4.681	7.809	3.612
		N	15	15	15	15	15
170	4	*Avg.*	**0.788**	**67.56**	**37.38**	**36.68**	**72.19**
		± s	0.010	0.74	3.791	2.725	1.658
		V	1.312	1.10	10.142	7.428	2.297
		N	15	15	15	15	15
	8	*Avg.*	**0.766**	**63.29**	**33.72**	**37.69**	**60.83**
		± s	0.009	0.77	3.092	4.661	3.685
		V	1.160	1.22	9.171	12.366	6.059
		N	15	15	15	15	15
	12	*Avg.*	**0.756**	**59.99**	**32.420**	**36.760**	**59.350**
		± s	0.011	0.75	3.392	4.261	3.885
		V	1.436	1.25	10.462	11.591	6.545
		N	15	15	15	15	15
190	4	*Avg.*	**0.784**	**63.55**	**34.44**	**39.86**	**72.05**
		± s	0.007	1.34	2.766	4.169	3.296
		V	0.846	2.11	8.031	10.458	4.575
		N	15	15	15	15	15
	8	*Avg.*	**0.765**	**61.56**	**30.53**	**38.99**	**65.62**
		± s	0.010	0.92	3.266	3.969	2.596
		V	1.246	1.49	10.697	10.179	3.956
		N	15	15	15	15	15
	12	*Avg.*	**0.756**	**58.32**	**29.76**	**37.18**	**63.67**
		± s	0.005	1.17	2.166	5.569	5.296
		V	0.679	2.01	7.278	14.978	8.317
		N	15	15	15	15	15
210	4	*Avg.*	**0.739**	**66.25**	**28.17**	**33.16**	**73.15**
		± s	0.007	0.68	2.766	4.169	3.296
		V	0.981	1.02	9.819	12.571	4.506
		N	15	15	15	15	15
	8	*Avg.*	**0.691**	**61.09**	**22.89**	**29.97**	**67.64**
		± s	0.021	0.70	2.455	4.262	3.458
		V	3.032	1.15	10.725	14.220	5.112
		N	15	15	15	15	15
	12	*Avg.*	**0.666**	**53.63**	**20.84**	**20.62**	**51.95**
		± s	0.017	0.61	2.754	2.261	3.478
		V	2.584	1.13	13.214	10.965	6694
		N	15	15	15	15	15

Avg., Average; ±s, standard deviation; V, coefficient of variation; N, Sample number; the compression loss in longitudinal direction. All data in Variance and one-way ANOVA tests were done in confidence level p<0, 05.

Table 1 lists the Brinell hardness results in different directions for untreated and treated wood specimens. Results revealed that surface hardness of hornbeam wood decreased with increased temperature and duration. Hardness values in the longitudinal, radial, and longitudinal sections of wood treated at 170 ºC for 4 h were approximately 38, 37, and 73 N/mm^2, respectively. When the duration was increased for the same exposure temperature, hardness values in the different sections decreased to a greater extent for 4 and 12 h durations than they did for the 8 hrs duration.

Table 2. Hardness losses and density loss results in different directions for heat-treated hornbeam wood.

Heat Treatment	Density loss (%)	Brinell Hardness Loss (%)		
		Tangential	Radial	Longitudinal
170 °C 4 hours	0.76	16.98	15.77	13.12
170 °C 8 hours	3.53	16.74	24.92	26.79
170 °C 12 hours	4.79	18.80	27.81	28.57
190 °C 4 hours	1.26	11.95	23.31	13.29
190 °C 8 hours	3.65	13.87	32.02	21.03
190 °C 12 hours	4.79	17.87	33.73	23.37
210 °C 4 hours	6.93	26.75	37.27	11.96
210 °C 8 hours	12.97	33.80	49.03	18.59
210 °C 12 hours	16.12	54.45	53.60	37.48

For the hornbeam wood tested, the minimum density loss of 0.76% occurred at treatment conditions of 170 ºC and 4 h, whereas the maximum density loss of 16.12% occurred at treatment conditions of 210 ºC and 12 h. The minimum decreases in surface hardness in the tangential, radial and longitudinal sections were 11.95% at 190 ºC for 4 h, 15.77% at 170 ºC and 4 h, and 11.96% at 210 ºC and 4 h, respectively. At conditions of 210 ºC and 12 h, the maximum decreases in surface hardness in the tangential, radial and longitudinal sections were 54.45%, 53.6%, and 37.48%, respectively.

In general the results of this study on the effect of heat treatment on Hornbeam are compatible with the findings in literature on the effect of heat treatment on different wood species. Yildiz (2002) determined that the greatest decreases in hardness values were observed when beech and spruce samples were treated at 180 ºC for 10 h. For beech samples, hardness decreases of 25.9%, 45.1%, and 41.8% were observed for longitudinal, radial, and tangential directions, respectively. For spruce, hardness decreases of 19.7%, 43.0%, and 42.5% were observed for longitudinal, radial, and tangential directions, respectively. Korkut *et al.* (2007) found that maximum hardness loss was obtained for samples Scots pine (*Pinus sylvestris* L.) treated at 180 ºC for 10 h, i.e., 40.99% in the longitudinal direction, 27.41% in the radial direction, and 38.96% in the tangential direction.

CONCLUSIONS

Hornbeam is a very dense wood species and significant mass losses were found after heat treatment resulting in a decrease of the density. The characterization of the effects of density loss on compression strength and hardness was an important goal of this study. Treatment conditions of 210 ºC and 12 h resulted in the maximum losses of compression strength parallel to the grain and of Brinell hardness in all three dimensions, i.e., tangential, radial, and longitudinal dimensions. The maximum loss of hardness occurred in the tangential direction, and the minimum loss was observed in the longitudinal direction. The results showed that the decreases of compression strength and hardness were related to the extent of density loss. While the maximum density loss observed was 16.12% at 210 ºC and 12 hour, at these heat-treatment conditions, the compression strength approximately decreased 30% and hardness values in tangential, radial, and longitudinal directions approximately decreased by 55%, 54%, and 38%, respectively. Hence, it was conclude that there might be a relationship between changes of these wood properties. Heat – treated wood has a growing market in outdoor applications like exterior cladding, windows and door joinery, garden furniture, and decking. There are also many indoor applications for heat – treated wood such as flooring, paneling, and kitchen furnishings and interiors of bathrooms and saunas. Because it loses strength, heat – treated wood is not recommended for head – bearing constructions.

REFERENCES

Anonymous, 1976. TS 2470, Wood–sampling methods and general requirements for physical and mechanical tests, T.S.E. Turkey.

Anonymous, 1976. TS 2471, Wood–determination of Moisture Content for Physical and Mechanical Tests, T.S.E. Turkey.

Anonymous, 1976. TS 2472, Wood–determination of density for physical and mechanical tests, T.S.E. Turkey.

Anonymous 1976. TS 2479, Wood–determination of Static Hardness, T.S.E. Turkey.

Anonymous 1976. TS 2595, Wood–determination of Ultimate Stress in Compression Parallel to Grain, T.S.E. Turkey.

Aydemir, D. 2007. The Effect of Heat Treatment on Some Physical, Mechanic and Technological Properties of Uludag Fir (*Abies bornmülleriana* Mattf.) and Hornnbeam (*Carpinus betulus* L.) Wood. Master Thesis, Zonguldak Karaelmas University, Zonguldak, Turkey.

Bekhta, P.; Niemz, P. 2003. Effect of high temperature on the change in color, dimensional stability and mechanical properties of spruce wood. *Holzforschung* 57(5): 539–546.

Boonstra, M.J; Acker, J.; Tjeerdsma, B.F; Kegel, E. 2007. Strength properties of thermally modified softwoods and its relation to polymeric structural wood constituents. *Annals of Forest Science* 64: 679-690

Boonstra, M.J.; Acker, J.; Kegel, E.; Stevens, E. 2007. Optimisation of a two-stage heat treatment process: durability aspects. *Wood Science and Technology* 41(1): 31-57.

Boonstra, M.J.; Tjeerdsma, B.F.; Groeneveld, H.A.C. 1998. Thermal modification of nondurable wood species: 1. The PLATO technology; Thermal modification of wood, *In Proceedings of 29th Annual meeting*, Maastricht-The Low Countries, 14-19 May, Doc. No. IRG/WP/98–40123.

Bourgois, J.; Bartholin, M.C.; Guyennet, R. 1998. Thermal Treatment of Wood: analysis of the obtained product. *Wood Science and Technology* 23(4): 303-310.

Ewert, M.; Scheiding, W. 2005. Thermally modified timber properties and application. *Holztechnologie* 46: 22-29.

Gailliot, F.P. 1998. Extraction and product capture in natural product isolation. *Humana Press Journals* 1: 59-68.

Gunduz, G.; Korkut, S.; Sevim Korkut, D. 2007. The effects of heat treatment on physical and technological properties and surface roughness of Camiyani Black Pine (*Pinus nigra Arn. subsp. pallasiana var. pallasiana*) wood. *Bioresource Technology* 99: 2275-2280.

Gunduz, G.; Niemz, P.; Aydemir, D. 2007. Specific Gravity and Equilibrium of Moisture Content Changes in Heat Treated Fir (*Abies nordmanniana subsp. bornmülleriana Mattf.*) Wood, *10th Int. IUFRO Div 5: Wood Drying Conference*, 26-31 August, 2007, v.5, 54-62.

Hinterstoisser, B.; Schwanninger, M.; Stefke B.; Stingl, R.; Patzelt, M. 2003. Surface analyses of chemically and thermally modified wood by FT-NIR. In: Acker, V.J., Hill, C. The 1st European conference on wood modification. *Proceeding of the first international conference of the European society for wood mechanics* 15-20 April, 2003, Gent-Belgium, pp: 65–70.

Kartal, S.N.; Hwang, W.J.; Imamura, Y. 2007. Water absorption of boron-treated and heat-modified wood. *Journal of Wood Science* 53(5):454-457.

Kocaefe, D.; Chaudhry, B.; Poncsak, S.; Bouazara, M.;Pichette, A. 2007. Thermogravimetric study of high temperature treatment of aspen: effect of treatment parameters on weight loss and mechanical properties. *Journal of Materials Science* 42(3):355-361.

Korkut, S.; Bektas, I. 2008. The effects of heat treatment on physical properties of Uludag fir (*Abies bornmuellerinana* Mattf.) and Scots pine (*Pinus sylvestris* L.) wood. *Forest Products Journal* 58(3): 95-99.

Korkut, S. 2007. The effects of heat treatment on some technological properties in Uludag fir (*Abies bornmuellerinana* Mattf.) wood. *Building and Environment* 43(4): 422-426.

Korkut, S.; Akgül, M.; Dündar, T. 2007. The effects of heat treatment on some technological properties of Scots pine (Pinus sylvestris L.) wood. Bioresource Technology 99(6): 1861-1868.

Korkut, S.; Kök, M.S.; Sevim Korkut, D.; Gürleyen, T. 2008. The effects of heat treatment on technological properties in Red-bud maple (*Acer trautvetteri* Medw.) wood. *Bioresource Technology* 99 (6): 1538–1543.

Mitchell, P.H. 1998. Irreversible property changes of small loblolly pine specimens heated in air, nitrogen, or oxygen. *Wood and Fiber Science* 20(3): 320–335.

Poncsak, S.; Kocaefe D.; Bouzara, M.; Pichette, A. 2006. Effect of High Temperature Treatment on the Mechanical Properties of Birch (*Betula pendula*). *Wood Science and Technology* 40(8): 647-663.

Raimo, A.; Kuoppala, E.; Oesch, P. 1996. Formation of the main degradation compounds groups from wood and its components during pyrolysis. *Journal Analytical and Applied Pyrolysis* 36: 137–148.

Sevim Korkut, D.; Korkut, S.; Bekar, I.; Budakçı, M.; Dilik, T.; Çakıcıer, N. 2008. The effects of heat treatment on physical properties and surface roughness of Turkish Hazel (*Corylus colurna* L.) wood. *International Journal of Molecular Sciences* (IJMS) 9(9): 1772-1783.

Tjeerdsma, B.F.; Boonstra, M.; Militz, H. 1998. Thermal modification of non-durable wood species 2. Improved wood properties of thermal treated wood, *In Proceedings of 29th Annual meeting, Maastricht-The Low Countries*, 14-19 May, Doc. No. IRG/WP/98–40124.

Unsal, O.; Ayrilmis, N. 2005. Variations in compression strength and surface roughness of heat-treated Turkish river red gum (*Eucalyptus camaldulensis*) wood. *Journal of Wood Science* 51: 405–409.

Viitaniemi, P.; Lamsa, S. 1996. Modification of wood with heat treatment. *VTT Building Technology* 1: 1-7.

Weiland, J.J.; Guyonnet, R. 2003. Study of chemical modifications and fungi degradation of thermally modified wood using DRIFT spectroscopy. *Holz als Roh-und Werkstoff* 61: 216-220.

Yıldız, S. 2002. Physical, mechanical, technological and chemical properties of Beech (*Fagus orientalis*) and Spruce (*Picea orientalis*) wood treated by heat. Ph.D. Thesis, Black Sea Technical University, Turkey.