DECAY RESISTANCE, PHYSICAL, MECHANICAL, AND THERMAL PROPERTIES OF HEATED ORIENTAL BEECH WOOD

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ABSTRACT

Heat treatment of Oriental beech (*Fagus orientalis*) wood was carried out by hot air in an oven for 2, 6, and 10 h at 125, 155, and 185°C. After heat treatment; decay resistance, oven dry density, modulus of rupture (MOR), compression strength parallel to grain (CSPG), and thermal characteristics of Oriental beech wood were investigated.

Our results showed that heat treatment caused a decrease in oven dry density values of Oriental beech wood specimens. Heat treatment improved decay resistance of Oriental beech

wood. Moreover, higher temperature and durations resulted in lower mass loss of wood after decay test. MOR values of heated Oriental beech decreased with increasing temperature and durations. CSPG values of Oriental beech decreased after heat treatments except for 2 and 6 hours heating at 125°C. According to the thermal analysis results, thermal properties of heated Oriental beech wood were preserved except for heated Oriental beech wood at 185°C for 6 and 10 hours.

KEYWORDS: Heat treatment, Oriental beech, decay resistance, oven dry density, MOR, CSPG, thermal characteristics.

INTRODUCTION

Wood has been preferred for residential construction since ancient times because of its natural beauty and excellent properties, such as, high specific strength, heat insulation, and ease of handling and processing (Su 1997). But, wood is much more easily degraded by environmental agents, including fire, biological organisms, water, and light, than many man-made materials (Kiguchi and Evans 1998). Preservative treatment is effective and can extend the service life of wood and wood products (Ahmed and Moren 2012). However, faced with increasing environmental pressure, worldwide wood manufactures started to gradually decrease the amount chemicals used in wood treatment and are looking for alternative ways of wood modification. The heat treatment of wood at high temperature, as a wood modification method, seems to be an eco-friendly and viable alternative (Vukas et al. 2010). The maximum temperature during heat treatment is varied from 180 to 280°C and from 15 minutes to 24 hours depending on the process, wood species, sample size, moisture content of the wood, desirable mechanical properties, resistance to biological attack and the dimensional stability of the final product (Kamdem et al. 2002). During heat treatment of lumber at temperatures around 200°C large changes in the wood properties take place. Heat treated wood exhibits better dimensional stability, better resistance to biodegradation, lower equilibrium moisture content and a brownish color. Heat- treated wood has been commercialized for outdoor applications such as paneling, garden furniture and decking. However, it is well known that distinct losses in mechanical properties can occur (Sundqvist 2004). Cellulose, hemicelluloses and lignin are the main structural elements of wood and heat treatment involves degradation of these components to different levels. While the hemicelluloses are the component that degrades to the highest extent (Finnish Thermowood Association 2003), lignin that holds the wood cell is the least heat sensitive component of the wood (Forsman 2008). Therefore, heat treated wood has a higher percentage share of lignin than normal wood (Vukas et al. 2010). When wood is heat treated the color of wood changes acquiring a darker tonality which is often caused by the formation of color degradation produced from hemicelluloses (Sehlstedt-Persson 2003, Sundqvist 2004). The color of wood is important from the aesthetic viewpoint for the consumers. Depending on cultural factors and income level, wood products may sell more solely due to their color. Heat treatment is an inexpensive alternative to darken wood to imitate more expensive exotic species (Sevim Korkut et al. 2013). In this study, it was aimed to investigate decay resistance, some physical properties such as oven dry density, some mechanical properties such as modulus of rupture (MOR) and compression strength parallel to grain (CSPG), and thermal characteristics of Oriental beech wood after heat treatment.

MATERIAL AND METHODS

Preparation of test specimens and chemicals

Wood specimens measuring 20 (radial) x 20 (tangential) x 360 (longitudinal) mm, for the MOR test, 20 (radial) x 20 (tangential) x 30 (longitudinal) mm for the CSPG test, 20 (radial) x 20 (tangential) x 20 (longitudinal) mm, for the oven dry density test, and 15 (radial) x 25 (tangential) x 50 (longitudinal) mm for the decay test were prepared from air-dried sapwood of Oriental beech. The fungal decay test was made using a white rot fungus, *Coriolus versicolor* (COV) (L. ex Fr.) Quel [FFPRI 1030]. For the thermal test, wood flour was prepared by grinding small wood pieces in a Wiley mill with a 50 meshes.

Heat treatment

Heat treatment was performed using a temperature-controlled laboratory oven. Three different temperatures (125, 155, and 185°C) and three treatment durations (2, 6, and 10 h) were applied to wood specimens under atmospheric pressure and in the presence of air.

Decay resistance test

The fungal decay resistance test was made according to JIS A-9201 (1991) using a white rot fungus, *C. versicolor* (COV) (L. ex Fr.) Quel [FFPRI 1030]. Wood specimens were sterilized with gaseous ethylene oxide after measuring the initial dry weights. The wood specimens of the same treatment were placed in a glass jar which contained a medium of 250 g quartz sand +80 ml nutrient solution which was composed of 3 g $MgSO_47H_2O$, 2 g KH_2PO_4, 10 g malt extract, and 5 g peptone per 1000 ml distilled water with fungal mycelia growing on it. Then, they were incubated at 26°C for 12 weeks. Test results were expressed as a percentage of mass losses of wood specimens due to fungal attacks after decay test.

Oven dry density test

Oven dry density values of non-heated (control) and heated Oriental beech wood specimens were determined according to TS 2472 (1976). Oven dry density values of wood specimens were calculated with the following equation:

$$d_0 \left(\frac{g}{cm^3} \right) = \frac{W_0}{V_0} \tag{1}$$

where: d_0 - oven dry density,
$\quad\quad\quad$ W_0 - oven dry weight of non-heated and heated wood specimens,
$\quad\quad\quad$ V_0 - oven dry volume of non-heated and heated wood specimens.

Modulus of rupture test

The MOR of wood specimens was determined according to TS 2474 (1976). Wood specimens had been conditioned at 20°C and 60 % RH for two weeks prior to testing.

The MOR of wood specimens was calculated by using the following equation:

$$MOR \left(\frac{N}{mm^2} \right) = \frac{3 \times P \times I}{2 \times b \times h^2} \tag{2}$$

where: P - the maximum load (N),
$\quad\quad\quad$ I - the span (mm),
$\quad\quad\quad$ b - the width of specimen (mm),
$\quad\quad\quad$ h - the thickness of specimen (mm).

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Compression strength parallel to grain test

The compression strength parallel to grain test was determined according to the TS 2595 (1977) standard by using a 4000-kp capacity universal test machine, and applying 6 mm.min^{-1} loading time. Before the test, wood specimens had been conditioned at 20°C and 60 % RH for two weeks.

Thermal analysis test

Differential thermal analysis (DTA) and thermogravimetry (TG) were carried out under argon at a heating rate of 10°C.min^{-1} and a purge rate of 50 mL.min^{-1} using a LABSYS TG-DTA analyzer (France). The temperature was heated from the room temperature to 600°C. During the heating and pyrolysis of about 10 - 15 mg of sample, the mass loss was monitored continuously. Onset and inflection temperatures of the pyrolysis were recorded by the analyzer for each treatment group. The rate of mass loss as a function of time was derived from a TG curve resulting in a derivative TG curve.

Evaluations of test results

The decay resistance, oven dry density, MOR, and CSPG values of wood specimens after heat treatment were evaluated by a computerized statistical program composed of analysis of variance and following Duncan tests at the 95 % confidence level. Statistical evaluations were made on homogeneity groups (HG), of which different letters reflected statistical significance.

RESULTS AND DISCUSSION

Decay resistance of heat treated wood

Decay test results of non-heated and heated Oriental beech are given in Tab. 1. Heat treated Oriental beech wood showed considerable resistance to the decay fungus compared to that of the non-heated control specimen. Weiland and Guyonnet (2003) have proposed two reasons for improvements in decay resistance of wood due to heat treatment. One is reticulation of some molecules produced during heat treatment, such as furfural. The second reason, lignin renders wood substrate which is unrecognizable by fungal enzymes. While the highest mass loss was obtained as 40.81 for non-heated Oriental beech, the lowest mass losses were recorded as 14.91 with heated for 10 h at 185°C. Our results showed that higher temperature and durations resulted in lower mass losses of Oriental beech. Šušteršic et al. (2010) investigated heat treated Scots pine specimens that were exposed to fungal decay using the brown rot fungus *Poria placenta* and determined the weight losses due to fungal degradation. They found that weight losses are well correlated with the intensity of heat treatment. Another similar study, Hakkou et al. (2006) found that decay durability is strongly correlated to mass losses due to thermal degradation.

Tab. 1: Mass losses of Oriental beech after decay test.

Heat treatment (°C)	Time (h)	Mass losses* (%)			
		Mean	SD	HG	Change (%)
Control	-	40.81	7.76	A	-
125	2	32.03	5.40	B	21.52
	6	27.12	4.52	BC	33.55
	10	25.44	4.38	BCD	37.67

	2	24.75	5.35	BCD	39.36
155	6	20.98	4.21	CDE	49.60
	10	19.87	3.86	CDE	51.32
	2	16.73	4.31	DE	59.11
185	6	16.21	4.85	DE	60.28
	10	14.91	3.94	E	63.47

*Ten replicates were made for each treatment group. SD: Standard deviation, Duncan: 0.05, HG: Homogeneous group, HG obtained by statistical analysis with similar letters reflecting statistical insignificance at the 95 % confidence level.

Welzbacher et al. (2007) investigated the effect of heat treatment conditions on wood decay durability at different temperatures (180, 200, 210, 220 and 240°C). They found that decay resistance for a given treatment intensity was better at higher temperatures. Our results are in good agreement with these researchers' findings. In our study, while mass loss of non-heated Oriental beech wood was 40.81 after the decay test, mass losses of heat treated Oriental beech changed from 14.91 to 32.03. There was a statistical difference between non-heated and heated wood specimens. In our study, non-heated and heat treated wood specimens for 2,4, and 6 h at 125 °C were classified as "moderately resistant" to *Coriolus versicolor*, and other all heat treated (at 155 and 185 °C) Oriental beech wood specimens were classified as "resistant" to *Coriolus versicolor* according to ASTM 2017 (2014) standard. Tripathi et al. (2014) investigated decay resistance of heat-treated *Pinus roxburghii* and *Mangifera indica* wood against brown (*Oligoporus placentus*) and white rot fungi (*Trametes versicolor*). They found that heat treatment at 160°C for 8 and 12 hours, 190°C for 4, 8 and 12 hours and 210°C for 4 and 8 hours improved decay resistance of wood to be "resistant" against both decay fungi. Resistance to decay in heat-treated wood is probably due to the loss of hemicellulose polymers in the cell wall. As shown earlier, the more weight loss in the heating process, the more durable the heat-treated wood (Rowell et al. 2009). Mohareb et al. (2012) reported a good correlation between the decreasing wood weight losses with the observed increase in lignin content which allows using the lignin content as a marker for wood durability during heat treatment. The same tendencies were noted for the correlation between the holocellulose reduction in the heat treated wood specimens and its decay resistance.

Oven dry density of heat treated Oriental beech

Oven dry densities of non-heated and heated Oriental beech wood specimens are given in Tab. 2. The assumption has been that wood quality for building material, depended mainly on its density. However, there is a close correlation between mechanical properties, hardness, abrasion resistance, and heat value of wood on one hand, and density on the other (Kollmann 1968).

Tab. 2: Oven dry density of Oriental beech after heat treatment.

Heat treatment (°C)	Time (h)	Oven dry density* (g.cm⁻³)			
		Mean	SD	HG	Change (%)
Control	-	0.623	0.094	A	-
	2	0.620	0.085	A	-0.48
125	6	0.615	0.068	A	-1.28
	10	0.612	0.081	A	-1.76

155	2	0.614	0.079	A	-1.44
	6	0.610	0.082	A	-2.16
	10	0.577	0.073	A	-7.35
185	2	0.596	0.065	A	-4.30
	6	0.588	0.054	A	-5.56
	10	0.547	0.057	A	-12.19

*Ten replicates were made for each treatment group. SD: Standard deviation, Duncan: 0.05, HG: Homogeneous group, HG obtained by statistical analysis with similar letters reflecting statistical insignificance at the 95 % confidence level.

Wood density is also an important factor in determining the possible uses of wood. For example, strength, flexibility, and surface hardness of heavy wood are greater than light wood. It gives better protection against corrosive effects. In some cases, it is better for wood to be soft, because it is easier to process, and has lower shrinkage and swelling. This can be possible when wood is light (Ors and Keskin 2008). Oven dry densities of Oriental beech wood decreased 0.48 to 12.19 % after heat treatment. The highest decrease of oven dry density was observed when wood specimens were treated with a temperature of 185°C for 10 h. Although the lowest oven dry density value was 0.547 g.cm^{-3}, which is 12.19 % lower than that of non–heated Oriental beech wood, no statistical difference was found between non-heated and heated wood specimens. Our results showed that oven dry densities of Oriental beech wood decreased with temperature and time of treatment which is in agreement with earlier data for Rowan wood (Korkut and Budakci 2010), Turkish hazel wood (Sevim Korkut et al. 2008), Camiyani black pine wood (Gunduz et al. 2008), European Hophornbeam wood (Korkut et al. 2009), *Pinus nigra* wood (Guller 2012), red-bud maple wood (Sevim Korkut and Guller, 2008), Anatolian black pine wood (Akyildiz et al. 2009). The depolymerization reactions of wood polymers are the main cause of the density decreases (Guller 2012). According to Vital and Lucia (1983), the main reason for the reduction in density was the degradation of hemicelluloses, which are less resistant to heat than cellulose and lignin. Furthermore, as far as density decrease is concerned, Boonstra et al. (2007) believed that the degradation of hemicelluloses into volatile products and the evaporation of extractives are the main reasons.

MOR of heat treated Oriental beech

The modulus ruptures of non-heated and heated Oriental beech wood are given in Tab. 3. It is clear from this study that the MOR values of Oriental beech decreased with increasing the temperature and durations.

Tab. 3: MOR of Oriental beech after heat treatment.

Heat treatment (°C)	Time (h)	MOR* (N.mm^{-2})			
		Mean	SD	HG	Change (%)
Control	-	118.4	13.2	A	-
125	2	116.9	11.7	A	-1.27
	6	115.8	10.0	A	-2.20
	10	115.2	8.9	A	-2.70
155	2	116.0	12.5	A	-2.03
	6	114.5	13.1	A	-3.29
	10	113.8	10.2	A	-3.88

	2	110.9	12.9	AB	-6.33
185	6	102.7	11.6	AB	-13.26
	10	90.6	8.3	B	-23.47

*Ten replicates were made for each treatment group. MOR: Modulus of rupture, SD: Standard deviation, Duncan: 0.05, HG: Homogeneous group, HG obtained by statistical analysis with similar letters reflecting statistical insignificance at the 95 % confidence level.

The same results were found by some researchers (Tiryaki and Hamzacebi 2014, Gunduz et al. 2009, Gunduz and Aydemir 2009, Ozcifci et al. 2009, Korkut 2008). The highest decrease of MOR was observed when wood specimens heated with a temperature of 185°C for 10 h. The lowest MOR strength value was 90.6 N.mm^{-2}, which is 23.47 % lower than that of non–heated Oriental beech wood. According to our results, except for Oriental beech heated for 10 h at 185°C, no statistical difference was found between non-heated and all heated wood specimens. With 2, 6, and 10 h of treatment at 125 and 155°C, the MOR reduction was very small. The relative decrease of MOR was between 1.27 to 3.88 % for 2, 6, and 10 h at 125 and 155°C. However, it reached 13.26 % for 6 h at 185°C and 23.47 % for 10 h at 185°C. The first reason for the loss of strength is the degradation of hemicelluloses, which are not as stable to the heat as cellulose and lignin. The close relationship between hemicellulose content and bending strength was reported by a number of researchers (Winandy and Morrell 1993; Winandy and Lebow 2001, Esteves et al. 2008). In the literature, there are many studies about the effects of heat treatment on MOR loss of heat treated wood. Kamperidou et al. (2014) reported a 25.90 % decrease in MOR values in heat treated Scots pine wood for 8 h at 200°C. Gunduz and Aydemir (2009) found a 47.2 % decrease in MOR values in heat treated Camiyani Black pine for 6 h at 200°C. Korkut and Hiziroglu (2009) reported a 31.86 % decrease in MOR values in heat treated Hazelnut wood for 10 h at 180°C. Gunduz et al. (2009) reported a 7.42 % decrease in MOR values in heat treated for 2 h at 160°C wild Pear (*Pyrus elaeagnifolia* Pall.) wood. Shi et al. (2007) found a reduction in MOR values ranging from 0 to 49 % in spruce, pine, poplar and birch woods depending on wood species and heat treatment conditions. Korkut (2008) reported a 29 % reduction in MOR values in heat treated Uludag Fir for 10 h at 180°C. Korkut et al. (2008) reported a 31.8 % reduction in MOR values in heat treated Red-bud maple (*Acer trautvetteri* Medw.) wood for 10 h at 180°C. Findings of the previous research on MOR of heat treated wood are not always compatible with each other because, heat treatment temperature, treatment time, specimen size, treatment method, and chemical composition of wood affect MOR loss of heat treated wood. Our results showed that an average MOR loss of 1.27 to 23.47 % has been found for heat treated Oriental beech wood. In general, the results of this study on the effect of heat treatment on MOR of Oriental beech are compatible with the findings of previous studies related effect of heat treatment on MOR. Temperatures over 150°C modify the physical and chemical properties of wood permanently. Having higher treatment temperature, yield enhanced lower strength properties (Mitchell 1988). Our results showed that MOR loss was 13.26 to 23.47 % for 6 and 10 h heated at 185°C. Also, Jämsä and Viitaniemi (2001) reported that at temperatures over 150°C the strength properties start to weaken and wood becomes more brittle and bending strength decrease by 10–30 %. Therefore, the use of heat-treated wood in load-bearing constructions is limited. MOR values are important for designing wood constructions (Yildiz et al. 2004). It can then be concluded that wood treated at high temperatures and for long durations should not be used for load-bearing purposes (Gunduz and Aydemir 2009).

CSPG of heat treated Oriental beech

The compression strength parallel to grain of non-heated and heated Oriental beech wood is given in Tab. 4. Our results showed that CSPG values of Oriental beech were generally decreased after heat treatment except for, 2 and 6 h heated at 125°C. Compression strength parallel to grain values of Oriental beech increased 5.73 and 0.70 % for 2 and 6 h heated at 125°C, respectively. In similar study, Yildiz et al. (2006) reported a slight increase in CSPG values in heat treated beech wood for 6 h at 130°C. Kol (2010) reported a 4.2 % increase in compression strength values in heat treated pine for 2 h at 212°C. Kamperidou et al. (2014) reported a 13.76 % increase in compression strength values in heat treated Scots pine for 4 h at 200°C. However, these observations contradict some of the reports in the literature. Unsal and Ayrilmis (2005) reported that the CSPG of river red gum specimens decreased about 19.0 % heated at 180°C for 10 h. Korkut (2008) reported that CSPG of Uludag fir wood decraased 29.41 % after heat treatment with 180°C for 10 h treatment. Gunduz et al. (2009) reported that percentages of compression strength losses for 2, 4, and 6 h were found to be 7.42, 12.38, and 13.71 % at 160°C and 11.16, 16.49, and 18.73 % at 180°C. According to our results, the highest decrease of CSPG values were observed when samples were treated with a temperature of 185°C for 10 h. But, there is no statistical differences between non-heated and heated wood specimens. The lowest compression strength value was 46.9 $N.mm^{-2}$ which is 18.85 % lower than that of non-heated Oriental beech wood.

Tab. 4: CSPG of Oriental beech after heat treatment.

Heat treatment (°C)	Time (h)	CSPG* ($N.mm^{-2}$)			
		Mean	SD	HG	Change (%)
Control	-	57.8	8.9	A	-
125	2	61.2	9.4	A	5.73
	6	58.2	8.5	A	0.70
	10	57.3	6.1	A	-0.87
155	2	57.5	7.0	A	-0.52
	6	57.2	5.9	A	-1.04
	10	56.0	8.8	A	-3.11
185	2	55.3	5.7	A	-4.32
	6	48.6	6.3	A	-15.92
	10	46.9	7.6	A	-18.85

*Ten replicates were made for each treatment group. CSPG: Compression strength parallel to grain, SD: Standard deviation, Duncan: 0.05, HG: Homogeneous group, HG obtained by statistical analysis with similar letters reflecting statistical insignificance at the 95 % confidence level.

Generally, the results of this study on the effect of heat treatment on CSPG of Oriental beech are compatible with the findings of previous studies related effect of heat treatment on CSPG. The decrease of compression strength was due to the holocellulose content degradation, in which the first constituent affected was probably the hemicellulose (Silva et al. 2013). If the impact of the heat treatment on the studied mechanical properties is observed cumulatively, it can be noticed that the effects are very different. This may be because of a number of factors, and it raises many questions, one which stands out is the question of change of the chemical composition of wood and its impact on each individual property. Another question is to what extent the lower humidity of thermally modified wood can do to help to prevent deterioration of mechanical properties (Popadić et al. 2010).

Thermal characteristics of heat treated Oriental beech

Thermal degradation characteristics of the wood could change with the variation in chemical structure. To investigate the effect of heat treatment on the mass loss profile of Oriental beech several differential thermal analysis (DTA) and thermogravimetry (TG) were performed under argon atmosphere with heating rate of $10°C.min^{-1}$ by using LABSYS TG-DTA analyzer (France).
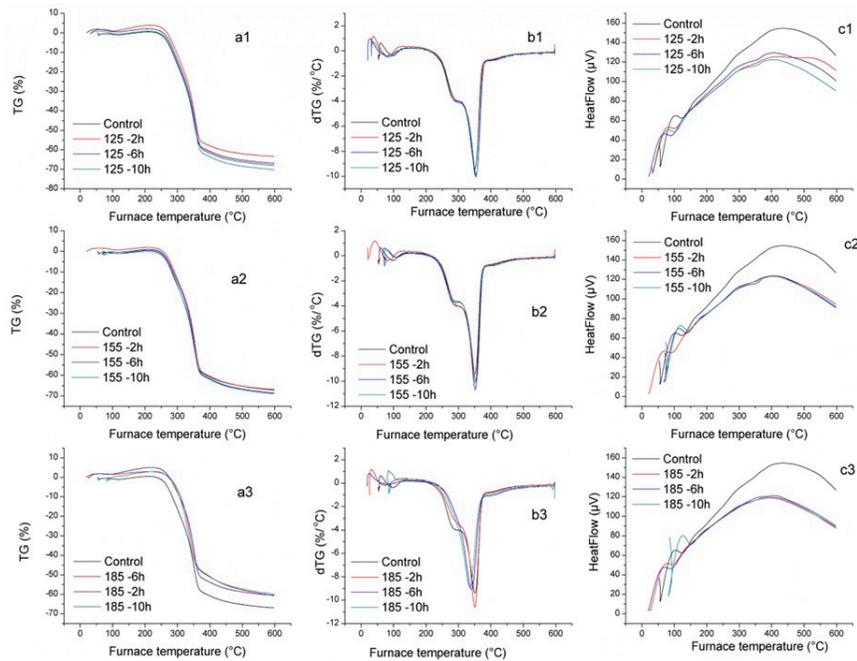
Fig. 1: a) thermogravimetry (TG), b) first derivative of thermogravimetry (DTG) curves c) Thermal analysis (DTA) of non–heated (control) and heat–treated wood.

Fig. 1 shows the TG curves (a1, a2, and a3), first derivative of TG curves (b1, b2, and b3) and DTA curves (c1, c2, and c3) of Oriental beech wood specimens heat treated at 125°C, 155°C and 185°C. The residual char (%) content and maximum (T_{max}, °C) and initial temperature (T_i, °C) of the pyrolysis are listed in Tab. 5.

As reported in literature, thermal degradation processes for wood consist of three stages (Beall and Eickner 1970, Tomak et al. 2012). In first stages; below 200°C noncombustible gases including water vapor is eliminated. As seen in TG curves (a1, a2, and a3 in Fig. 1) and DTG curves (b1, b2, and b3 in Fig.1), significant mass loss for Oriental beech specimens which were heated at different temperatures, was not observed below 200°C. The results obtained from DTA curves were indicated that the endothermic peaks which correspond to desorption of physically bound water at between 100 - 150°C were observed for all specimens.

As seen in Fig. 1 (c1, c2, and c3) the position of these peaks was not constant. In second stages; cellulose, hemicelluloses, and lignin degrade between 230–378°C. The hemicelluloses are decomposed totally in temperature ranges between 200-280°C and converted into gaseous products (CO, CO_2, and condensable vapors) (Sinha et al. 2000). Also, it was reported that the

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Tab. 5: Residual char after pyrolysis and maximum and initial temperature of the pyrolysis.

Heat treatment (ºC)	Time (h)	Residual char (%)	T_i (°C)	T_{max} (°C)
Control	-	32.96	240	353
125°C	2	32.70	238	353
	6	32.36	233	353
	10	29.88	236	353
155°C	2	33.72	234	352
	6	31.15	233	353
	10	30.69	236	352
185°C	2	39.81	247	350
	6	39.75	249	341
	10	39.88	252	334

thermo degradation of the hemicelluloses resulted the acetic acid formation. Acetic acid acts as depolymerization catalyst and accelerates the decomposition of polysaccharides (Brosse et al. 2010, Esteves and Pereira 2008). In this stage, lignin and cellulose are converted into gas, tar, and char in temperature range between 250-300°C (Pétrissans et al. 2014). In this stage, from the TG curves (a1 in Fig. 1) mass loss of non-heated Oriental beech was calculated as 57.42 %. For the Oriental beech heated at 125 and 155°C, similar mass loss values with the non-heated wood specimen were obtained. Mass losses for the heated specimens at 125 and 155°C were calculated in range between 55.7 - 60.7 % and 58.1 - 58.9 % respectively, for all exposure times. On the contrary, in these stage mass losses of 2, 6, and 10 h heated Oriental beech at 185°C were calculated as 60.1, 47.81, and 46.89 % respectively. Similar observations were achieved for heated specimens from the DTG curves (b1, b2, and b3 in Fig. 1). Although, the maximum degradation temperature (T_{max}) of heated specimens at 125 and 155°C were nearly same with the non-heated specimen, maximum degradation temperature was not constant for the wood specimens heated at 185°C. As seen in Tab. 5, T_{max} values for non-heated specimens and heated specimens at 125 and 155°C were calculated as 353°C. In the case of the specimens heated at 185°C, T_{max} values shifted to lower temperatures with respect to the non-heated wood specimen. T_{max} values of the heated specimens at 185°C during 2, 6, and 10 h exposing time were found as 350, 341, and 334°C, respectively. T_{max} was lover for wood treated with 185°C/6 or 10 h because of the thermal degradation of the constituents of the Oriental beech wood began during the treatment and it was higher at 185°C/6 or 10 h with respect to the other conditions. Higher heat treatment temperature and longer exposure time may cause the shifting of T_{max} values to the lower temperature. From the DTG curves, it was observed that there was knee at around 291 except for heated specimens at 185°C for 6 and 10 h. Although the DTG curves of the specimens heated at 125°C was nearly identical, the DTG curves of the heat-treated specimens at 155°C differ slightly. The intensity of the knee at around 291°C decreased with the increasing of exposure time for the heated specimens at 155°C. Residual char content of the wood specimens are listed in Tab. 5. As seen in Tab. 5 residual char contents of the heated specimens at 185°C were higher than that of non-heated and the other heated specimens. The differences of the thermal characteristics of the heated specimens are attributed to the chemical changes during the treatment. The exposing time and temperature effects the final chemical compositions of the heated Oriental beech specimens. As reported in literature, despite lignin is most stable biopolymer found in woody product, some chemical changes could be occurred in lignin structure even at 175°C (Tumen et al. 2010). Tumen and coworkers also found that the lignin content of heated wood specimens increases

with the increase of exposing time (Tumen et al. 2010). The hemicelluloses are the biopolymer which thermally decomposed easily with respect to other biopolymers even at low temperatures. Both chemical changes in lignin and hemicelluloses after thermal treatment affected the thermal degradation characteristics and other properties of the Oriental beech. Similar to the results obtained in literature, our results shows that the thermal degradation characteristics of the specimens heated at 185°C changed more than the specimens heated at 125 and 155°C.

CONCLUSIONS

Decay resistance, oven dry density, MOR, CSPG, and thermal properties of heat treated Oriental beech were investigated. Our results showed that heat treatment decreased oven dry density of Oriental beech wood. Moreover, higher temperatures and durations gave lower oven dry density of Oriental beech after thermal treatment. Decay resistance of Oriental beech wood improved a considerable amount after heat treatment. Our results showed that higher temperature and durations resulted in lower mass losses of Oriental beech after the decay test. While non-heated (control) and treatment for 2, 4, and 10 h at 125°C showed "moderate resistance", other all heat treated Oriental beech wood specimens showed "resistance" according to ASTM D2017 (2014) classification. The MOR of Oriental beech decreased by up 1.27 to 23.47 % after heat treatments. Higher temperatures and durations resulted in lower MOR values of Oriental beech after heat treatments. Except for 2 and 6 h heating at 125°C, CSPG of other treatment groups decreased by up 0.52 to 18.85 %. The National Design Specification for Wood Construction requires a 10 – 20 % reduction in allowable design stress, depending on the mechanical property under consideration. In our study, except for MOR of Oriental beech heated for 10 h at 185°C, MOR and CSPG of other all heated Oriental beech met the NFPA requirements for design purposes. Thermo gravimetric analysis showed that heated at 185°C changed the thermal degradation characteristics of the wood specimen more than the heated at 125 and 155°C. From the DTA curves, the knee at around 291°C was observed for all wood specimens except for heated wood specimens at 185°C for 6 and 10 h. The other important result was the maximum degradation temperature of all wood specimens was found as 353°C except for heated wood specimens at 185°C for 6 and 10 h.

In conclusion, our results showed that while oven dry density, MOR, and CSPG of Oriental beech decreased to some extent after heat treatments, decay resistance of Oriental beech considerably improved. Although, MOR and CSPG of Oriental beech decreased after heat treatments, they still remain suitable for design purposes. Heat treatments at 155 and 185°C of Oriental beech revealed a clear improvement in resistance against *Coriolus versicolor*. The decay resistance of Oriental beech against decay fungi was improved from "moderately resistant" to "resistant" after heat treatments at 155 and 185°C. Thermal degradation characteristics of Oriental beech wood heated at 185°C showed differences from other treatment temperatures.

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