Investigating The Relationship Between Some Mechanical Properties and Weight Loss in Heat Treated Woods

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ABSTRACT

In this study, the effects of heat treatment on modulus of rupture (MOR), modulus of elasticity (MOE) and weight loss (WL) of beech (*Fagus orientalis* Lipsky.) and spruce (*Picea orientalis* (L.) Link.) woods were examined, and relationship between WL and the mechanical properties of the treated woods were determined by various analyzes. The experimental samples were selected from naturally grown woods in the Black Sea region of Turkey. Heat treatment was subjected to samples in an oven at three different temperatures (130, 160 and 190 ºC) and three different durations (2, 6 and 10 h) under atmospheric pressure. The results indicated that treated samples had lower MOR and MOE compared to control samples. An increase in exposure temperature and duration decreased MOR and MOE. WL of the samples increased with increasing treatment temperature and duration. Also, percentage reduction in MOR and MOE values showed a strong correlation with percentage increase in WL. The correlation coefficient (R) was determined as 0.89 between MOR and WL, and almost 0.90 between MOE and WL.

Keywords: Heat treatment, modulus of elasticity, modulus of rupture, weight loss

Isıl İşlemli Odunlarda Bazı Mekanik Özellikler ve Ağırlık Kaybı Arasındaki İlişkinin Araştırılması

ÖZ

Bu çalışmada, Doğu kayını ve Doğu ladini odunlarının eğilme direnci, elastikiyet modülü ve ağırlık kaybı üzerine ısıl işlemin etkileri incelendi ve ısıl işlemli odunların ağırlık kaybı ve mekanik özellikleri arasındaki ilişki çeşitli analizler yoluyla belirlendi. Deneysel örnekler Türkiye'nin Doğu Karadeniz bölgesinde doğal olarak yetişen ağaç türlerinden seçildi. Isı muamelesi atmosferik basınç altında üç farklı sıcaklık (130, 160 ve 190 ºC) ve üç farklı sürede (2, 6 ve 10 saat) bir fırında örneklere uygulandı. Sonuçlar muamele edilmiş örneklerin kontrol örneklerine kıyasla daha düşük eğilme direnci ve elastikiyet modülüne sahip olduğunu gösterdi. Maruz kalınan sıcaklık ve sürede bir artış eğilme direnci ve elastikiyet modülünde azalmaya yol açtı. Örneklerin ağırlık kayıpları artan muamele sıcaklığı ve suresi ile artış gösterdi. Ayrıca, eğilme direnci ve elastikiyet modülü değerlerindeki azalma yüzdesi, ağırlık kaybındaki artış yüzdesi ile güçlü bir ilişki gösterdi. Korelasyon katsayısı (R) eğilme direnci ve ağırlık kaybı arasında 0.89, elastikiyet modülü ve ağırlık kaybı arasında ise yaklaşık olarak 0.90 olarak tespit edildi.

Anahtar Kelimeler: Isıl işlem, elastikiyet modülü, eğilme direnci, ağırlık kaybı

1. INTRODUCTION (GİRİŞ)

Although wood is a material having excellent properties, it suffers a number of unfavorable aspects because of its hygroscopic characteristics. To eliminate these unfavorable aspects of wood, numerous studies have been conducted for a long time [1]. Based on the results of the studies was developed some methods generally named as "wood modification methods" [2], such as Thermowood in Finland, rectification in France, oil-heat treatment in Germany and Plato-wood in Netherlands [3,4]. One of these methods is to heat the wood at high temperatures [5].

It can be said that heat treatment aims to improve some natural quality properties of the wood, such as the resistance to biodegradation and dimensional stability [6]. In addition to this, favorable changes occur in some physical properties of wood as a result of heat treatment. For example, it provides lower hygroscopicity, lower equilibrium moisture content, a more attractive appearance, and an increase in biological resistance to decay [7]. Because of such advantages, it was reported that heat treated wood is suitable for garden, kitchen and sauna furniture, cladding on wooden buildings, floor material, ceilings, doors and window joinery, and other outdoor and indoor applications [3]. On the other hand, heat treatment also causes some undesirable changes in the wood structure. Especially, weight losses, which are related to the degradation of wood polymers depending on heat treatment temperature and duration, occur as a result of heat treatment, and the losses often reduce the mechanical properties of wood, including MOE and MOR [8,9,10]. The effect of heat treatment in wood starts to appear especially at temperatures over 150 ^{o}C

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and thus wood becomes more fragile [11,12]. For this reason, heat treated wood is generally not preferred in load-bearing constructions [12]. Heat treatment also causes varying amounts of WL depending on exposure temperature and duration. WL of spruce (*Picea abies*) was detected as 0.8% and 15.5% at 120 ^{o}C and 200 ^{o}C for 24 h, respectively. WL of beech (*Fagus sylvatica*) was 8.1% and 9.8% at 150 ^{o}C and 200 ^{o}C, respectively [13].

A study carried out by Srinivas and Pandey [14] investigated the effect of heat treatment on MOR and MOE of rubberwood and Silver oak. It was reported that heat treatment had a negative impact on MOR and MOE of wood species. In another study, Yapıcı and Ulucan [15] examined the MOR and MOE of heat treated Anatolian chestnut wood. They observed that MOR and MOE values significantly decreased due to heat treatment. Tankut et al. [16] studied the mechanical properties of heat-treated Black pine, Scotch pine, Oriental spruce, Iroko, and Ash. They detected that heat treatment caused an average reduction of 19% for MOE and 24% for MOR. Tiryaki and Hamzacebi [17] reported that heat treatment process adversely affected MOR and MOE of spruce and beech woods. Jiang et al. [18] found that the average MOR values of heat-treated oak wood decreased by 17.0–56.7% compared to the control samples with an increase in heat treatment temperature and duration, while the MOE values were slightly affected from the process. Esteves et al. [19] determined that MOE of pine wood decreased with increasing WL due to heat treatment. The decrease was less than 5% until about 4% of WL, but then increased and reached 16% for about 6% of WL. Curling et al. [20] reported the powerful relationship between WL and reduction in MOR and MOE caused by heat treatment.

The main goal of this study was to reveal the relationship between some mechanical properties (MOR and MOE) and WL of beech (*Fagus orientalis* Lipsky.) and spruce (*Picea orientalis* (L.) Link.) woods due to heat treatment.

2. MATERIAL AND METHOD (MATERYAL VE YÖNTEM)

2.1. Material (Materyal)

Beech (*Fagus orientalis* Lipsky.) and spruce (*Picea orientalis* (L.) Link.) logs used as the experimental materials in this study were obtained from the Black Sea region of Turkey. Lumber from the logs was prepared in the sawmill of Forestry Faculty, Karadeniz Technical University. The samples cut into to appropriate sizes for MOR and MOE experiments. Then, the samples were conditioned in a climate controlled room at 20 ± 2 ºC and 65 ± 5 % relative humidity for reaching the moisture content of about 12 %.

2.2. Application of Heat Treatment (Isıl İşlem Uygulaması)

The samples were subjected to heat treatment at three temperature levels (130 ^{o}C, 160 ^{o}C and 190 ^{o}C) for three time spans (2h, 6h and 10h) in a temperature controlled laboratory type heating oven at an accuracy of ± 1 ºC under atmospheric pressure. Then, treated and untreated samples were conditioned to constant weight at 65 ± 5 % relative humidity and 20 ± 2 ºC temperature.

2.3. MOR and MOE Tests (Eğilme Direnci ve Elastikiyet Modülü Testleri)

MOR and MOE values of beech and spruce samples were determined using a universal test device. MOR and MOE tests were performed according to TS 2474 [21] and TS 2478 [22], respectively. Maximum force during fracture in the determination of MOR was designated as Newton (N). During MOR experiment, MOE values were also determined. MOR and MOE (N/mm^2) were calculated using Eq. (1) and Eq. (2), respectively.

$$MOR = (3/2).(Fmax.L/b.h^2) \quad (1)$$

$$MOE = F.L^3/4.b.h^3.f \quad (2)$$

Where, Fmax is maximum force at the time of fracture (N), F is force in the elastic part (N), L is distance between support points (mm), b is sample width (mm), h is sample thickness (mm) and f is the amount of bending (mm).

2.4. Determination of WL (Ağırlık Kaybının Belirlenmesi)

The test samples of MOR and MOE were dried in a heating oven at 103 ± 2 ºC prior to heat treatment. Oven-dry weight of the samples was measured with ± 0.01 g sensitivity. After heat treatment process, oven-dry weight of the same samples was measured again. WL of samples due to degradations caused by heat treatment was next calculated by Eq. (3).

$$WL(\%) = 100(m_b - m_a)/m_b \quad (3)$$

In Eq. (3), m_b is the oven-dry mass of the sample before heat treatment and m_a is the oven-dry mass of the same sample after heat treatment.

2.5. Data Analysis (Veri Analizi)

Statistical data assessment was carried out by means of the analysis of variance. Thus, the effects of treatment temperature and exposure duration on MOR, MOE and WL were determined. Then, DUNCAN test was applied and homogenous groups were constituted if there was a meaningful difference ($P \leq 0.05$) among the groups. Moreover, a correlation analysis was carried out to determine the relationship between percentage decrease in strength values and percentage increase in WL. All data were analyzed by using a SPSS 11.5 (Statistical Package for The Social Science)

3. RESULTS AND DISCUSSION (BULGULAR VE TARTIŞMA)

Table 1 shows the change in MOE and MOR values of wood samples for varying treatment temperature and durations.

revealed that average values of MOR and MOE were lower in heat treated samples compared to control

Table 1. MOR and MOE values obtained as a result of temperature and durations of heat treatment (Isı muamele sıcaklık ve süresinin bir sonucu olarak elde edilen eğilme direnci ve elastikiyet modülü değerleri)

Temperature (ºC)	Time (h)	MOR (N/mm^2)						MOE (N/mm^2)					
		Beech			Spruce			Beech			Spruce		
		Avg.	SD	HG	Avg.	SD	HG	Avg.	SD	HG	Avg.	SD	HG
Control	-	108.15	3.86	**A**	78.07	3.70	**F**	13969.3	1231.5	**A**	7919.7	1032.5	**G**
	2	105.02	4.36	**A**	73.29	4.61	**G**	13301.4	2011.7	**AB**	7425.9	1452.5	**GH**
130	6	101.43	4.46	**B**	69.81	4.02	**H**	12696.6	1935.6	**BC**	6746.4	1366.7	**GHI**
	10	95.02	4.81	**C**	65.29	4.81	**JK**	11940.4	1612.2	**CD**	6632.3	472.0	**HI**
	2	96.94	2.27	**C**	67.17	2.43	**HI**	12088.8	1753.3	**CD**	6878.5	333.3	**GHI**
160	6	94. 00	4.94	**C**	66.14	1.99	**IJ**	11253.5	1344.6	**DE**	6649.5	353.4	**HI**
	10	87.88	3.68	**D**	61.71	2.69	**KL**	10660.4	1238.3	**E**	6524.9	522.1	**HI**
	2	86.60	3.33	**D**	63.50	3.38	**JK**	10567.4	1372.0	**EF**	6536.8	1046.3	**HI**
190	6	83.18	3.79	**E**	61.99	2.59	**KL**	10438.0	1282.5	**EF**	6229.1	789.1	**HI**
	10	78.21	4.25	**F**	58.76	2.97	**L**	9456.6	1012.7	**F**	5641.6	887.2	**I**

Avg: average; SD: standard deviation; Number of samples used in each test (20); $p < 0.05$; HG: Homogeneity groups

samples. In addition, it is clear that MOR and MOE of spruce samples were lower than that of beech.

From the average values of the measured properties of untreated and heat treated samples, it can be shown that the averages for all variations in most cases decreased with increasing treatment temperature and duration (Table 1). It was

Table 2 shows percentage decrease in MOR and MOE values of treated samples compared to control samples, and percentage increase in WL of post-heat treatment compared to weight of the pre-heat treatment.

Percentage changes in MOR, MOE and WL of beech and spruce woods subjected to heat treatment for different temperature and durations are also illustrated Figure 1. measured properties of beech and spruce woods are is generally in agreement with the findings of previous studies carried out on this subject. In a study on heat treated

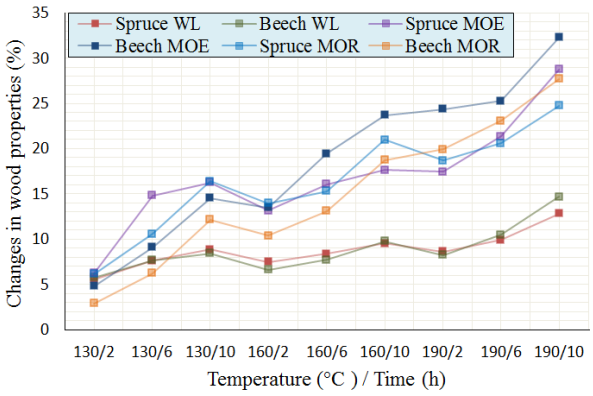

Figure 1. Percentage changes in MOR, MOE and WL of beech and spruce woods due to heat treatment (Isı muamelesinden dolayı kayın ve ladin odunlarının eğilme direnci, elastikiyet modülü ve ağırlık kaybında yüzde değişiklikler)

Table 2. Average percentage changes in the values of the measured parameters as a result of temperature and duration of heat treatment (Isı muamelesinin sıcaklık ve süresinin bir sonucu olarak ölçülen parametrelerin değerlerinde ortalama yüzde değişiklikler)

Temperature (ºC)	Time (h)	MOR (%)		MOE (%)		WL (%)	
		Beech	Spruce	Beech	Spruce	Beech	Spruce
	2	2.90	6.13	4.78	6.23	5.75	5.57
130	6	6.21	10.58	9.11	14.81	7.65	7.61
	10	12.14	16.38	14.52	16.26	8.44	8.84
	2	10.37	13.97	13.46	13.15	6.63	7.48
160	6	13.09	15.28	19.44	16.04	7.73	8.40
	10	18.75	20.95	23.69	17.61	9.74	9.51
	2	19.92	18.67	24.35	17.46	8.21	8.61
190	6	23.09	20.59	25.28	21.35	10.46	9.91
	10	27.69	24.73	32.30	28.77	14.65	12.79

As can be seen from Table 1 and Table 2, the maximum decrease in MOR among all variations was observed at heat treatment of 190 ºC for 10 h. The lowest MOR values obtained were 58.76 N/mm^2 and 78.21 N/mm^2 for spruce and beech samples, respectively, total reduction compared to control samples were calculated as 24.73% and 27.69% for spruce and beech, respectively. Similarly, the lowest MOE values were obtained as 5641.59 N/mm^2 and 9456.62 N/mm^2 in spruce and beech samples exposed to heat treated at 190 ºC for 10 h, respectively. The MOE loss, compared to the control, was 28.77% for spruce, and 32.30% for beech. In addition, WL of test samples was determined as 12.79% in spruce and 14.65% in beech for the same variations. These values were the highest WL percentages observed in all variations.

The findings of this study with regard to the effects of heat treatment on the spruce and beech by Yildiz [23], the highest decrease in MOE for spruce was found to be 41.5% at 200 ºC for 6 h. For beech, heat treatment at 200 ºC for 10 h resulted in 39% increase in MOE. In the same study, the highest decrease in MOR for beech and spruce was observed when wood samples were treated at 200 ºC for 6 h and 10 h. The decrease was 63.9% and 63.6% for beech and 63.8% and 72.7% for spruce at 6 h and 10 h, respectively. Similarly, Tiryaki and Hamzacebi [17] studied mechanical properties of spruce and beech after heat treatment. It was reported that increasing temperature and duration significantly decreased the MOR and MOE values. In another study on the mechanical properties of heat treated woods, Viitaniemi and Jamsa [24] stated that MOR of treated wood is reduced by up to 30% depending on the treatment conditions. An average decrease in MOR as high as 44-50% has also been reported by Bektha and Niemz [25].

For the effects of heat treatment on MOR and MOE, higher percentage decrease of MOR and MOE were found in beech compared to spruce. Likewise, percentage increase in WL of beech was greater than spruce in general. In terms of WL in beech and spruce at 200 ^{o}C, it was reported that WL of beech is higher 10% compared to WL of spruce [26,27]. This is likely to be related to the structure the hemicellulose units of hardwoods and softwoods. The hemicellulose units of hardwoods degrade more easily compared to those of softwood because they include more acetyl group compared to softwoods [28]

A correlation analysis was carried out to reveal relationship between percentage decrease in strength values and percentage increase in WL. The results of analysis are shown in Figure 2.

According to results of the analysis, it was determined that percentage decrease in strength and percentage increase in WL demonstrated a strong correlation. The correlation coefficient (R) was found as 0.89 between MOR and WL, and approximately 0.90 between MOE and WL. Thus, the determination coefficient (R^2) was calculated as 0.79 between MOR and WL, and 0.80 between MOE and WL. This indicates that at least 79% of the decrease in MOR and 80% of the decrease in MOE can be explained with increasing WL. Namely, the mechanical properties of wood species strongly depend on the increased WL due to heat treatment. In the previous studies, the similar results were obtained. Curling et al. [20] reported a powerful relationship between WL and reduction in MOR and MOE. Esteves et al. [19] found that MOE of pine wood decreased with increasing WL during heat treatment. The decrease was less than 5% until about 4% of WL, but increased subsequently and reached 16% for about 6% of WL. This reveals the power of the relation between mechanical properties and WL in heat treated woods.

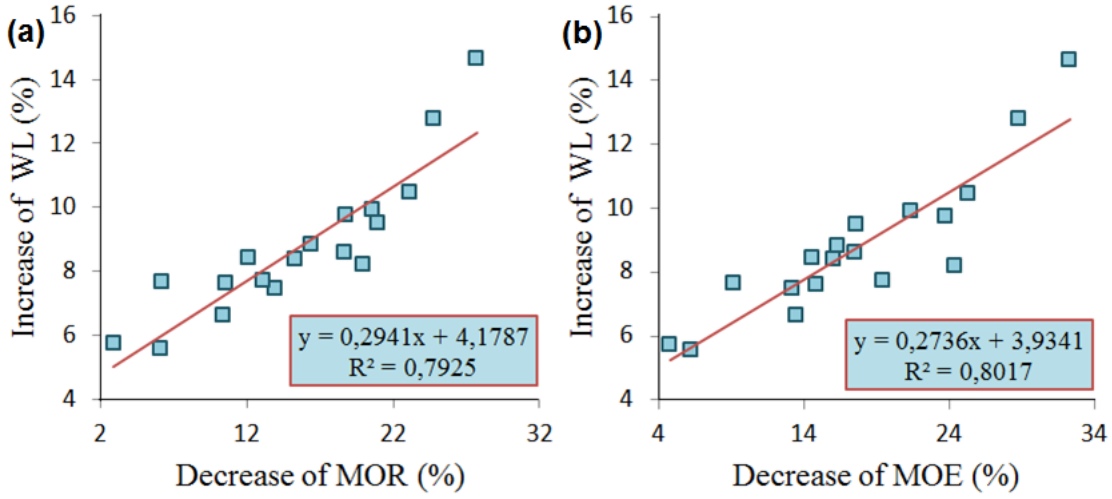

Figure 2. Relationship between percentage decrease in strength values and percentage increase in WL (a- relationship between MOR and WL, b- relationship between MOE and WL; $p < 0.01$) (Direnç değerlerindeki yüzde azalma ve ağırlık kaybındaki yüzde artış alasındaki ilişki (a-Eğilme direnci ve ağırlık kaybı arasındaki ilişki, b-Elastikiyet modülü ve ağırlık kaybı arasındaki ilişki; $p < 0.01$)

According to Brito et al. [29], the decrease in strength values is mainly due to the loss of the hemicellulos during heat treatment. It was reported that hemicellulose is less resistant to heat treatment compared to cellulose and lignin because it has a low molecular weight and branching structure [13,30]. According to Mburu et al. [31], the strength properties of wood also vary depending on anatomical features of wood species and treatment methods.

4. CONCLUSIONS (SONUÇLAR)

This study focused on the relationship between some mechanical properties (MOR and MOE) and WL of beech and spruce due to heat treatment.

The results of the study indicated that MOR and MOE values of spruce and beech decreased with increasing treatment temperature and exposure duration. On the other hand, WL of samples increased with increasing duration and temperature of heat treatment. The results also showed that increasing temperature and duration of heat treatment resulted in a greater reduction in the treated samples compared to the control samples for strength values. A strong correlation was also observed between decreasing strength values and increasing WL caused by heat treatment. While the value of R^2 between MOR and WL was 0.79, the corresponding value of MOE and WL was calculated as 0.80.

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