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THE EFFECT OF MASS LOSS ON MECHANIC PROPERTIES OF HEAT-TREATED PAULOWNIA WOOD

Bulent Kaygin, Gokhan Gunduz, Deniz Aydemir
Zonguldak Karaelmas University, Bartin Forest Faculty, Bartin, Turkey

ABSTRACT

In this study, the effect of mass loss on mechanic properties of Paulownia (*Paulownia elongata*) wood was investigated. For this study, three different temperatures (160, 180, and 200°C) and durations (3, 5, and 7 hours) were carried out. After heat treatment, the mass loss of the heat-treated samples were found and then it is determined how affected on mechanic properties of Paulownia wood The data obtained were analyzed using variance analysis, and then Tukey's test was used to determine the effect on mechanic properties of mass loss during heat treatment. The results show that mechanic properties were occurred decreasing in variation ration in relate with mass loss. While the maximum mass loss found was 9,78% at 200 °C and 7 hour, the compression strength, modulus of elasticity, bending strength and impact strength decreased about 17, 19, 78 and 88%, respectively. Hence, it is determined that the mass loss on mechanic properties of Paulownia wood significantly affected.

KEY WORDS: Paulownia wood, mechanic properties, mass loss, heat treatment.

INTRODUCTION

Paulownia elongata is a species of plant in the Paulowniaceae family. It is used as a forestry tree in North America and China. It is reportedly the fastest growing hardwood tree which are known to grow up to 15 or more feet in the first year. The wood is used as a lightweight alternative to Birch and other fast grown woods. Paulownia wood also resists splitting and warping in the drying process and can hold nails and screws without splitting. Furniture applications such as interior framing material and panels create a light yet sturdy product. The demand for lightweight furniture continues to grow. Decorative moldings can be made in intricate patterns. Paulownia has been a long favorite for many wood carvers. Paulownia can also be used for crown moldings, windows, drawers, log homes, humidors, pyrotechnic charcoal, Venetian blinds and surfboards. It is naturally rot and insect resistant, making it a great alternative for Teak wood and Western Red Cedar.

Heat treatment of wood at high temperature is one of the wood modification methods to improve the dimensional stability and bio durability of timber. It has been studied for years in Europe (Militz 2002, Rapp and Sailer 2000, Sailer et al. 2000, Syrianen and Kangas 2000). After treatment at 180°C or higher, chemical changes in lignin and hemicelluloses occur and

the treated wood becomes less hydroscopic (Tjeerdsma et al. 1998b, Kotilainen 2000; Aydemir 2007, Gunduz et al. 2008). As a result, the wood is more dimensional stabilized when the relative humidity changes (Yildiz 2002). It turns the wood to be less prone to fungi degradation as well (Dirol and Guyonnet 1993, Troya and De Navarrete 1994, Viitanen et al. 1994, Tjeerdsma et al. 1998a). Some studies showed the reduction in bending strength of the treated wood (Bengtsson et al. 2002, Santos 2000, Yildiz et al. 2002). The degree of such decrease is very dependent on the wood species to be treated, the maximum temperature reached in the process, and the holding time at that temperature, etc (Vernois 2001).

It is a fact that influence of heat treatment on strength properties of wood is complex and magnitude of effect is function of certain parameters such as exposure period, temperature, heating medium, wood moisture content and atmospheric pressure (Fengel and Wegener 1984). The process of heat treatment is generally accompanied by breakage of the lignin-polysaccaride complex by organic acids released from hemicelluloses (LeVan et al. 1990, Zaman et al. 2000). Winandy (1995) showed that the initial strength loss in wood appears to be related to the removal of side-chain hemicelluloses components. The loss of mass during heat treatment is considered to be attributable to water loss in the wood structure as a result of decreaseing availability of hydroxyl (OH) groups, the loss materials in the cell wall and the disintegration of hemicelluloses (Fengel and Wegener 1984; Kawamura et al., 1996). In addition to affecting the mechanical properties of wood, high temperature heat treatment has also been found to decrease its strength, surface hardness and abrasion strength (Aydemir 2007). To our knowledge, there is no information about the influence of mass loss which occurred during heat treatment on mechanical properties, such as compression strength, bending strength, modulus of elasticity in bending and impact bending strength of paulownia wood that is a fast grown in Turkey. Therefore, the main objective of this study is to evaluate the effect of mass loss on mechanic properties of heat treated paulownia wood, provide a preliminary data so that treated wood can be used more widely and effectively by the timber products industry.

MATERIAL AND METHODS

Materials

The Paulownia (Paulownia elongata) samples used during this study were obtained from a local sawmill in Kurucasile, Bartin, Turkey. According to TS2470, Small clear specimens were cut from the lumbers for compression strength parallel to grain (20x20x30 mm), modulus of elasticity in bending (20x20x360 mm) and impact bending strength (20x20x300 mm). Specimens were randomly divided into 9 treatment groups of having 30 specimens in each, in addition to non-treated samples as control group having 30 specimens were also considered for the tests. Heat treatments were carried out at three temperatures, namely 160°C, 180°C, and 200°C and for three time spans, 3 h, 5 h, and 7 h in a laboratory type heating unit controlled at an accuracy of ±10°C under atmospheric pressure. After heat treatment, treated and control samples were conditioned to 12% moisture contents (MC) in a climate room with a temperature of at 20 ± 20°C and a relative humidity of 65% (±5) (TS 642). The equilibrium moisture content of the samples was approximately 12% after conditioning. Prior to the test, the dimensions were measured to the nearest 0.001 mm and their weights were recorded to the nearest 0.01 g. Test for compression strength parallel to grain (CS) (TS 2475), modulus of elasticity in bending (MOE) (TS 2478), bending strength (BS) (TS 2474) and impact bending strength (IBS) (TS 2477) measurements were carried out for treated and untreated samples, based on Turkish Standards

(TS). Variance analysis was applied in the analysis of the results in this study. All statistical calculations were based on the 95% confidence level. ANOVA and Tukey's Multiple Range Tests show that all differences were significant.

RESULTS AND DISCUSSION

Tab. 1 displays result of tests for the control and heat treated samples for three temperature and duration. The effect of the heat treatment was significant for all the variables analyzed.

Tab. 1: Effect of mass loss on mechanic properties of heat treated paulownia wood

Temperature (°C)	Durations (Hours)	Statistical Data	CS ($N.mm^{-2}$)	MOE (N/mm^{-2})	BS (N/mm^{-2})	IB (N/mm^{-2})	Mass Loss (%)
Control	-	X	22.7	3931.2	38.5	8.1	-
		±s	1.8	316.6	4.7	0.1	-
		V (%)	8.3	8.0	12.3	15.1	-
160	3	X	22.9	3832.8	35.1	7.2	4.7
		±s	2.3	465.8	4.1	0.03	0.2
		V (%)	10.1	12.1	11.8	4.6	4.8
	5	X	21.9	3852.8	34.0	5.1	4.8
		±s	2.8	373.6	3.4	0.09	0.3
		V (%)	12.7	9.7	10.2	18.0	7.3
	7	X	20.6	3897.0	32.5	4.2	5.6
		±s	1.6	419.8	5.3	0.04	0.8
		V (%)	7.9	10.7	16.3	9.5	14.8
180	3	X	22.6	4002.2	31.9	5.0	5.6
		±s	3.4	348.7	4.6	0.06	0.7
		V (%)	15.0	8.7	14.4	11.7	12.9
	5	X	21.5	3908.6	28.4	4.7	5.9
		±s	1.5	389.8	4.2	0.03	0.6
		V (%)	7.2	9.9	15.0	7.3	11.5
	7	X	19.9	3386.7	21.8	3.8	7.0
		±s	2.9	486.2	2.3	0.04	0.7
		V (%)	14.5	14.3	10.6	9.8	10.5
200	3	X	20.8	3891.6	19.3	3.2	7.7
		±s	2.6	655.3	2.8	0.05	1.0
		V (%)	12.7	16.8	14.8	14.8	13.0
	5	X	19.0	3754.2	12.0	1.9	9.4
		±s	2.0	429.7	1.8	0.03	1.3
		V (%)	10.9	11.4	15.0	15.9	14.0
	7	X	18.4	3214.6	8.4	0.9	9.7
		±s	2.3	524.0	0.9	0.01	1.3
		V (%)	12.9	16.3	11.1	2.5	13.4

Avg., Average; ±s, standard deviation; V, coefficient of variation, All data in Variance and one-way ANOVA tests were done in confidence level $p < 0, 05$.

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. Based on the findings in this study all of the mechanical properties tested due to mass loss decreased with increasing temperature and time.

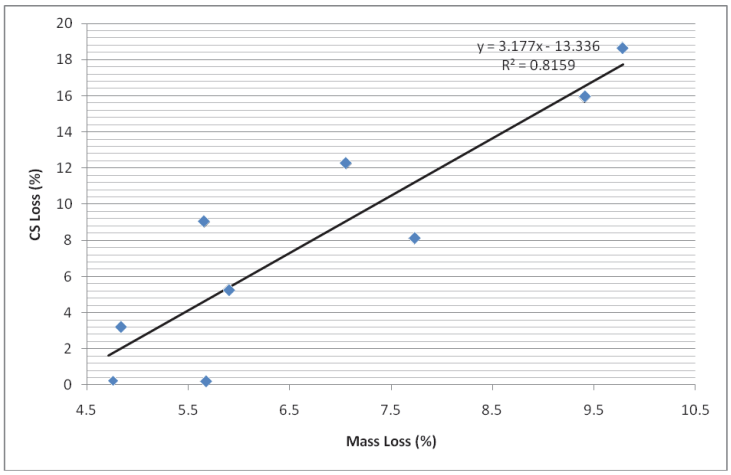

Fig. 1: The effect of mass loss on compression strength (CS) loss

According to Fig. 1, after heat treatment at 160°C for 3 h, the minimum loss of compression strength values showed a small decrease (0.15%) as mass loss was 4.71%. The greatest decrease ration in compression strength was observed as 18.68% when mass loss was 9.78% at a temperature of 200°C for 7 h. Gunduz et al. (2007) reported that the maximum decreases for all parameters were recorded at treatment conditions of 180°C 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 (*Eucalyptus camaldulensis* Dehn.) wood samples was 19.0% at treatment conditions of 180°C and 10 h.

According to Fig. 3, mass loss had an adverse effect on bending strength (BS) of heat treated paulownia wood. It can be seen that the decrease in BS was about 88% as mass loss was 9.78%. When the lowest mass loss of 4.71% occurred at conditions of 160°C at 3 hour, BS loss in same temperature was 8.73%. After heat treatment, the lowest decrease ration in MOE was observed as 2.50% as mass loss ration was minimum ration. Also, the highest reduction ration in MOE was 18.23% when mass loss was maximum ration. But it showed that MOE in 180°C for 5 hour was increased in 1.80%. It was said that MOE was affected less by temperature and mass loss increase as compared to other strength properties. Yildiz (2002) reported that the lowest bending strengths for beech and spruce were observed when the wood samples were treated at 200°C for both 6 and 10 hours. The decrease was 63.9% and 63.6% for beech and 63.8% and 72.7% for spruce, both treated for 6 and 10 hours at 200°C. The highest decrease in MOE for spruce was found to be 41.5% at 200°C for 6h. Beech samples exposed to heat treatment at a temperature of 200°C for 10h resulted in 39% increase of MOE.

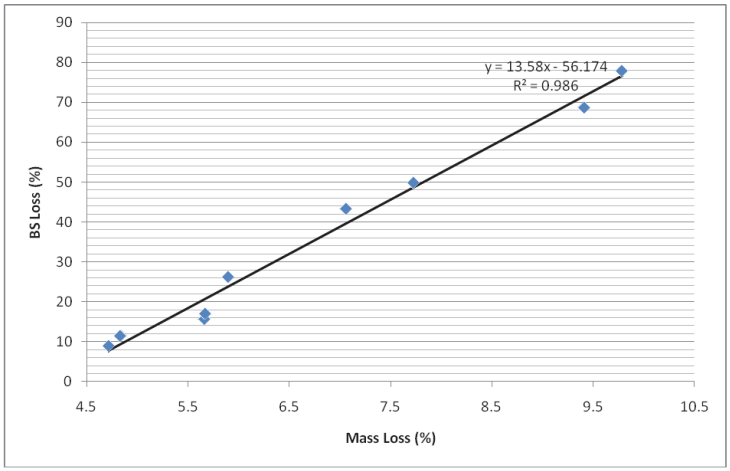

Fig. 2: The effect of mass loss on bending strength (BS) loss

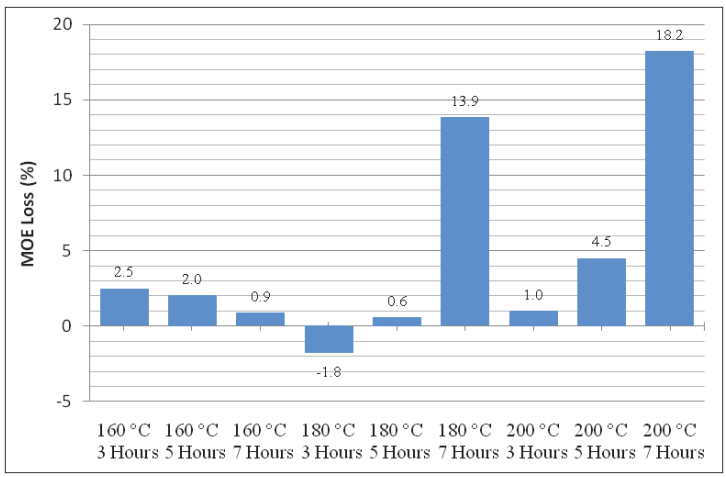

Fig. 3: The effect of mass loss on modulus of elasticity in bending (BS) loss

Korkut (2008) reported for Uludag fir that the lowest bending strength values were obtained in samples treated at 180°C for 10 hours (92.914 N.mm^{-2}). The bending strength loss compared to the control was 32.68%.

According to Fig. 3, the highest and lowest decrease in IBS was found to be 87.05% and 11.06% when mass loss ration was 9.78% and 4.71%. As seen as Fig. 3 and Tab. 1, it was emphasized that IBS was affected more by temperature and mass loss increase as compared to other strength properties. Korkut (2008a) reported for Hazelnut (*Corylus colurna* L.) that the lowest impact bending values were obtained in samples treated at 180°C for 10 hours (1.87 N.mm^{-2}). The impact bending strength loss compared to the control was about 55%.

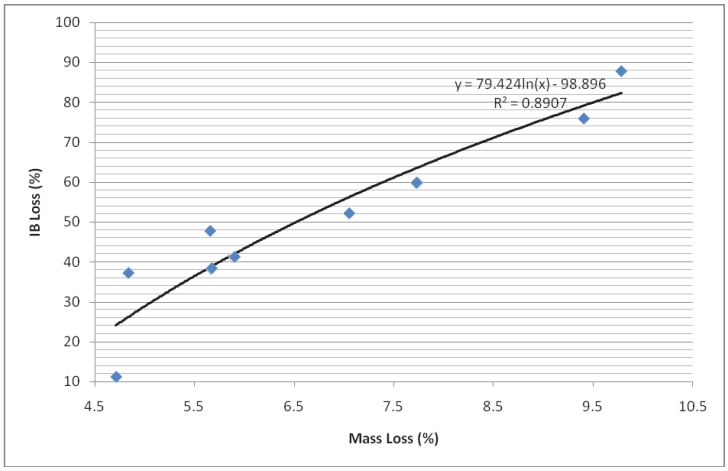

Fig. 4: The effect of mass loss on modulus of impact bending (IBS) loss

The decreases in the strength properties can be explained by the rate of thermal degradation and losses of mass as a result of treatment process. This is mainly due to the depolymerization reactions of wood polymers (Kotilainen 2000). The primary reason for the strength loss is the degradation of hemicelluloses, which are less resistant to heat than cellulose and lignin. It is well known fact that changes of hemicelluloses plays key roles in the strength properties of wood heated at high temperatures (Hillis 1984).

CONCLUSION

It was found that mass loss that occurred due to heat treatment decreased in compression strength, Bending Strength, Modulus of elasticity and Impact Bending Strength of paulownia wood which is a fast grown species. After heat treatment, when the lowest decrease was observed on all mechanic properties for 160°C at 3 hour, the highest decrease was determined to 200°C at 7 hour. The mass loss is mainly related with degradations of wood constitutes. So increasing mass loss of heat treated wood when temperature or duration increased. Simultaneously affects mechanic properties of wood. When fast grown wood species has been treated at high temperatures and long durations, it is recommended that such wood not be used structurally for load-bearing purposes. After heat treatment, Paulownia wood could be utilized by using proper heat treatment techniques with minimum losses in strength values for applications such as window frames, interior siding, decorative material where strength isn't an important factor.

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Corresponding Author:
Bulent Kaygin
Zonguldak Karaelmas University
Forest Faculty in Bartin
Department of Forest Industrial Engineering
74100 Bartin
Turkey
E-mail: bulentkaygin@karaelmas.edu.tr

Gokhan Gunduz
Zonguldak Karaelmas University
Bartin Forest Faculty
Bartin
Turkey

Deniz Aydemir
Zonguldak Karaelmas University
Bartin Forest Faculty
Bartin
Turkey