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Physical and Mechanical Properties of Laminated Veneer Lumber Manufactured by Poplar Veneer

M. Nazerian and M. Dahmardeh Ghalehno

Department of Wood and Paper Science and Technology, University of Zabol, Zabol 98615-538, Iran

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Abstract: Efficient usage of laminated veneer lumber (LVL) in the construction industry requires an understanding the effects of the heat treatment process on the physical and mechanical properties of LVL. It is well known that the heat treatment is often used to improve the dimensional stability of solid wood, but it cases to decrease mechanical properties of solid wood. However, this study aimed testing the physical and mechanical properties of LVL manufactured from heat-treated and untreated poplar veneers. The LVL samples were produced from poplar heat treated veneers (*Populus nigra*) in the seven ply form (3 mm each) by using urea-formaldehyde (UF) adhesive. Before manufacturing LVL, veneers were subjected to heat treatment at varying temperatures and for varying durations of heating. Significant differences were determined ($P \leq 0.05$) in the physical and mechanical properties of the LVLs. The results were recorded the lowest density increment as 29%, the lowest radial swelling as 48%, the lowest tangential swelling as 45% and the lowest longitudinal swelling as 33% for LVL manufactured from heat treated veneers at 180 °C for 5 h as compared to the control sample. The highest flat-wise and edge-wise modulus of rupture (MOR) (107.67 MPa and 102.1 MPa) and modulus of elasticity (MOE) (6,190 MPa and 6,017 MPa) were obtained in the control sample manufactured from untreated veneers. It was determined that modulus of elasticity was less sensitive than modulus of rupture of composite lumber to change due to increase in temperature and heat durations. According to the statistical analyses of variance, the mechanical and physical properties of LVL were more sensitive to temperature than duration of exposure.

Key words: Heat treatment, laminated veneer lumber (LVL), mechanical and physical properties, *Populus nigra,* poplar, urea-formaldehyde (UF) adhesive.

1. Introduction

Durability, mechanical properties and engineering performance of LVL are affected by many factors such as wood species, heat treatment and etc [1]. One of the original reasons to heat-treat wood and wood composites is to improve the properties of durability and to obtain a more dimensionally stable material by reducing the equilibrium moisture content. It is generally accepted that heat treatment also lowers the wet ability of wood materials [2-3]. Heat treatment results in varying amounts of weight loss, depending on the treatment temperature and time. For example, weight loss of beech (*Fagus sylvatica*) wood, treated at increasing temperatures, was as 8.1% and 9.8% at 150 °C and 200 °C, respectively [4]. Heat treatment reduces the tangential and radial swelling of wood. In general, desired changes start to appear at about 150 °C, and continue with increment in temperature in stages [5]. In bending strength, poplars compare favorably with common construction species such as pine and fir. This is especially true for oriented strand board (OSB), LVL, and structural composite lumber [6], so poplar can be used for structural and non-structural applications [7]. The LVL has been suggested as a good alternative for structural purposes. However, the results of researches about exposure durability of this material are contradictory to each other [8].

Wood and wood composites are useful

Corresponding author: M. Nazerian, Ph.D., research field: wood composite materials. E-mail: morteza17172000@yahoo.com.

M. Dahmardeh Ghalehno, M.Sc., research field: wood composite materials. E-mail: mmdahmardeh@yahoo.com.

constructional materials, but they have less desirable properties such as poor durability and poor dimensional stability. Heat treatment is an alternative method for improving these properties with no use of chemical additives. When wood is heated, chemical changes start to take place inside the wood structure. These changes result in decreased mechanical properties and increased dimensional stability. Therefore, the aim of this study was to determine the effects of heat treatment and heating duration of the veneers on the bending strength, modulus of elasticity, water absorption, and swelling of LVLs produced from poplar wood bonded with UF adhesive.

2. Materials and Methods

Poplar (*Populus deltoids,* 0.35 g cm^{-3}) logs with a diameter at breast height diameter (DBH. 1.3 m above ground) of 38-45 cm were obtained from the North part of Iran. The growth rate of this material averaged 1.6 rings per centimeter. Round logs (with moisture content of 130%) were cut into stocks without juvenile wood. After three months, veneers having dimensions of 5 mm × 100 mm × 360 mm were cut out of the stocks and were sanded on both sides with 50-grit sandpaper in belt-sanding machine. Then, veneers with dimensions of 3 mm × 100 mm × 360 mm were divided into nine treatment groups. The moisture content of the veneers before heat treatment was 8%. A number of veneers were subjected to heat treatment at 80, 130 and 180 °C for 1, 3, and 5 h in a small heating unit controlled to within ± 1 °C under atmospheric pressure. Before heat treatment, veneers were not dried in a dryer. After the heat treatment, the treated and untreated plies were conditioned to 12% moisture contents in a conditioning room at 23 ± 2 °C and with 65 ± 5% relative humidity. In order to obtain LVL with 20 mm thickness, 7 layers of veneers (3 mm thickness) were bonded with UF applied to one single surface of the veneer at the ratio of 180 g m^{-2}. At first, LVL panels were prepressed in cold press and then in hot press (at 140 °C) with pressure of 10 N mm^{-2} for 9 min.

The pressed pieces of the LVLs were transformed for density, dimensional stability, modulus of elasticity and bending strength tests with finished dimensions of 20 mm × 100 mm × 100 mm and 20 mm × 20 mm × 360 mm, respectively. Pressing was continued until a total of 450 samples were produced with 9 replicates for each test. Test samples were conditioned to achieve equilibrium moisture content at 23 ± 2 °C temperature and 65 ± 5% relative humidity prior to be tested for 2 weeks.

The dimensions and weights of the samples were measured. The air-dry density and dimensions of the samples were determined at 0.01 mm and 0.001 g sensitivity. The samples were soaked in water (20 ± 2 °C). After 24 h, radial swelling was measured from four different points and their average value was recorded as a single value. Also, the tangential and longitudinal swellings of the samples were calculated as a percentage. For static bending test, the samples were destructively tested in both flat-wise and edge-wise bending according to the ISO 16978 standards [9]. The loading speed was 1 mm/min.

For air-dry density, radial (thickness), tangential and longitudinal swelling, edge-wise and flat-wise MOR and MOE, all multiple comparisons were first subjected to an analysis of variance (ANOVA) and significant differences between mean values of control and treated samples were determined using Duncan's multiple range test. The significance of results was at 5%. The *t*-test with Bonferroni correction was used to determine whether or not the differences between the flat-wise and edge-wise MOR and MOE values according to the treatment temperature and time were significant.

3. Results and Discussion

Table 1 shows the values of the air-dry density, radial, tangential and longitudinal swelling of LVL manufactured from veneers treated under different treatment regimes. According to the averages, the physical properties decreased with increasing temperature and duration of heating time. The result

Table 1 The effect of heat treatment of veneers for different durations heating on physical and mechanical properties of the LVL.

Heat treatment	Time (h)	Unit	Air-dry density (gcm^{-3})	Swelling			Mechanical properties			
				Radial	Tangential	Longitudinal	⊥MOR (MPa)	⊥MOE (MPa)	‖MOR (MPa)	‖MOE (MPa)
Control		Mean	± 0.42 A	12.18 A	6.71 A	0.97 A	107.67 A	6,190 A	102.1 A	6,017 A
		sd	0.0036	0.40	0.51	0.005	9.5	42	9	72
80 °C	1	Mean	± 0.42 A	11.55 A	6.71 A	0.98 A	103.55A	6,168.3 A	95.8 B	6,010 A
		sd	0.0054	0.27	0.59	0.005	6.3	68.8	5.8	85.4
	3	Mean	± 0.417 A	11.47 A	6.57 A	0.96 A	89.7 B	6,012.2 B	82.5 C	5,971.1 A
		sd	0.0068	0.76	0.51	0.004	5.1	59.9	5.4	26.4
	5	Mean	± 0.417 B	10.28 B	6.49 A	0.96 A	78.4 C	5,894.3 C	74.8 D	5,773.8 B
		sd	0.0052	0.85	0.28	0.003	8.5	93.1	9.9	71.4
130 °C	1	Mean	± 0.362 B	9.79 BC	5.61 B	0.87 B	56.4 D	5,842.9 C	51.7 E	5,792.3 B
		sd	0.0054	1.04	0.30	0.003	3.7	39.51	51.7	73.56
	3	Mean	± 0.362 B	9.18 CD	5.35 B	0.86 B	54.5 D	5,330 D	50.5 E	5,272.7 C
		sd	0.0065	1.08	0.34	0.004	7.3	52.2	7.1	39.8
	5	Mean	± 0.36 C	9.46 C	5.26 B	0.85 C	34.8 E	5,266.7 DE	31.1 E	5,233.4 C
		sd	0.01	0.97	0.81	0.005	3.7	35.9	4.3	38.8
180 °C	1	Mean	± 0.334 D	8.55 DE	4.67 C	0.71 D	54.3 D	5,193.8 E	49 F	4,504.7 D
		sd	0.0035	0.81	0.51	0.004	3.7	308.8	5.2	58.8
	3	Mean	± 0.32 D	7.83 E	4.43 C	0.70 D	26.9 F	4,998.2 F	24.3 G	4,359 E
		sd	0.0052	0.73	0.36	0.009	4.5	48.8	3.4	64.9
	5	Mean	± 0.298 D	6.33 F	3.64 D	0.65 E	20.9 G	4,265.7 G	16.7 H	3,943 F
		sd	0.005	0.54	0.24	0.013	5.3	34.2	5.2	84.7

Groups with same letters in column indicate that there was no statistical difference ($P < 0.01$) between the samples according to Duncan's multiple range test. ⊥: flat-wise modulus of rupture and elasticity; ‖: edge-wise modulus of rupture and elasticity.

of ANOVA proved that the effect of temperature and duration of heating time on air-dry densities of LVL panels was significant with 0.05 probabilities. The air-dry density values of LVLs decreased with increasing temperature and heat treatment time of veneers under the mentioned conditions. The LVL made from heat treated veneers at a temperature of 180 °C for 5 h showed the lowest air-dry density values (0.298 g cm^{-3}). In contrast, the LVL manufactured from untreated veneers had the highest air-dry density (0.42 g cm^{-3}). Both LVL of heat treated veneers (at 80 °C and 130 °C) and untreated veneers had higher density values than those of solid wood from which LVLs were produced. The reason for higher density of the mentioned LVLs is related to the thickness loss of the panel due to the compression rate during pressing and the higher density of adhesive being used in panel production. Esteves et al. [10] studied the mass loss of heat treated maritime pine at temperatures between 170 °C and 200 °C during 2 to 24 hours and concluded that the mass loss increases with the treatment time and with the temperature, and the same mass loss can be obtained with different temperatures, depending on the treatment time.

The control sample had the highest average thickness, tangential and longitudinal swellings of 12.18%, 6.71% and 0.97%, respectively. The LVL with treated veneers at 80 °C for 1, 3 and 5 h had somewhat lower average swellings than others. The LVLs with heat-treated veneers at 130 and 180 °C for 5 h were found to have significantly lower average radial, tangential and longitudinal swellings. The highest decreases in swelling to radial, tangential and longitudinal directions were found to be 48%, 45% and 33%, respectively (Table 2), in the LVLs made from veneers treated at 180 °C for 5 h. Zivkovic et al. [11] showed that higher level of treatment temperatures yields proportionally greater stabilization effects. They obtained that the heat treated wood, when compared to genuine wood, exhibits a significant reduction of fibre saturation point and improvements in dimensional stability. The change in the physical properties was mainly influenced by the value of density of the LVL and thermal degrading of hemicelluloses. Theoretically,

Table 2 Percentage decrease of swellings and mechanical properties in LVL manufactured from poplar veneer following heat treatment for different durations.

Temperature (°C)	Time (h)	Air-dry density (%)	Swelling			Mechanical properties			
			Radial (%)	Tangential (%)	Longitudinal (%)	⊥MOR (%)	⊥MOE (%)	‖MOR (%)	‖MOE (%)
80 °C	1	0.6	5.0	0	0	4	0.35	6	0.1
	3	1.1	5.5	1.5	0.8	17	2.80	19	0.8
	5	1.2	15.6	2.7	0.8	27	4.80	27	4.0
130 °C	1	14	19.5	16	10.6	47	5.60	50	3.7
	3	15	25.3	20	11.3	49	13.9	51	12
	5	14	22.0	21	13.4	67	14.9	69	13
180 °C	1	21	30.0	30	27.0	49	16.1	52	25
	3	24	36.0	33	28.0	75	19.2	76	27
	5	29	48.0	45	33.0	81	31.0	84	34

⊥: flat-wise modulus of rupture and elasticity; ‖: edge-wise modulus of rupture and elasticity.

the available OH groups in hemicellulose have the most significant effect on the physical properties of wood. Heat treatment slowed water uptake and lowered water absorption by wood cell wall because of decrease in the amount of OH groups. As a consequence of the reduced number of hydroxyl groups, the swelling and shrinking became lower [12, 13]. These finding suggest that improvement of physical behavior of LVL produced from poplar veneers can be achieved by using heat treatment. The increase in dimensional stability for heat treated woods mainly is due to the decrease of hygroscopicity in view of the chemical changes at high temperatures. The decrease rates for arabinose, galactose, xylose, and mannose indicate that the high temperature decreases the equilibrium moisture of veneer and consequently the swelling of panels made of veneers [14]. Zhang et al. [15] showed that changing the character of wood from hydrophilic to more hydrophobic by hemicellulose extraction can also potentially improve dimensional stability in wood and wood-based composites. Also, Ates et al. [16] reported that all values of the physical properties were decreased with temperature and duration of process, and physical properties were strongly affected negatively by treatment temperature. They concluded that this result can be explained in terms of material losses in cell wall and hemicelluloses degradation depending on the applied high temperature after heat treatment.

The effect of temperature and heat durations on the mechanical properties of LVL was significant ($P \leq 0.05$) for flat-wise and edge-wise MOR and MOE (Table 1). The flat-wise MOR and MOE were lowest in laminated poplar manufactured from heat treated veneers at 180 °C during 5 h with 20.9 MPa and 4,265.7 MPa, followed by LVL produced from the treated veneers at 180 °C during 3 h. The flat-wise MOR and MOE values in LVL produced from the heat treated veneers at 180 °C during 5 h were 81% and 31%, respectively, lower than control samples (Table 2). Therefore, decreases of flat-wise static bending strength reached with increasing thermal treatment conditions. The highest flat-wise MOR and MOE values (107.67 MPa and 6190 MPa) were obtained in the laminated poplar with untreated veneers, followed by MOR and MOE of samples with treated veneers at 80 °C for 1 h.

The most decrease in edgewise MOR and MOE values of laminated poplar were observed at 16.7 MPa and 3,943 MPa when poplar veneers were treated at 180 °C for 5 h. The edge-wise MOR and MOE of LVL panels with veneers treated at 180 °C for 5 h were 84% and 34%, respectively, which were significantly ($P \leq 0.05$) lower than that of control sample (Table 2). These results can be explained with material loses in cell lumen and hemicellulose degradation due to applied height temperature [17]. Control sample had the highest edge-wise MOR and MOE (102.1 MPa and 6,017 MPa), which followed by LVL made from veneers treated at 80 °C for 1 h with MOR and MOE of 95.8 MPa and 6,010 MPa, respectively. On the other hand, a slight increase in MOR and MOE were observed on samples with veneers treated at 80 °C for 1, 3 and 5 h, respectively. In this case, temperature might have greater influence on strength properties than time. The strength of the laminated poplar was higher than that of solid poplar, but a dramatic diminution was observed above temperatures of about 180 °C. Similar results were reported by the other researchers in solid wood [18]. This research approved that the MOR and MOE of poplar LVLs were higher than those of corresponding solid materials. The increase is assumed to be due to glue usage and layered structure. One of the major problems is strength losses explained by thermal degradation rate and material loss [19]. The overall results in the strength on the laminated poplar tests for both the MOR and MOE seem to be greatly influenced by the combined densities of the laminated veneer, treatment temperature and treatment time. These values increase with the increases in density of the LVL. The strength of laminated wood decreases when wood is heated and increases when it is cooled. This effect was clearly achieved with the prolonged treatments. The least property affected was the MOE while the most affected one was the MOR (Table 2). This finding supports previous research that heat treatment causes important degradations of the material, resulting in a decrease of the hemicellulose content [10, 14, 15].

The diminutions in the strength properties are related to the rate of thermal degradation and losses of substance after the heat treatments. The decrease in strength is mainly due to the depolymerization reactions of wood polymers [20]. The primary reason for the strength loss is degradation of hemicelluloses, which is less stable to heat than cellulose and lignin. Changes or losses of hemicelluloses play key roles in strength properties of wood heated at high temperatures [21]. Nazerian et al. [14] reported that the decrease rates for arabinose, galactose and mannose at 180 °C heated wood veneers when compared to untreated veneers are remarkable. Arabinose, mannose, galactose and xylose, which are responsible for hemicelluloses formation [22], were significantly influenced by increasing temperatures. Higashihara et al. [23] found that hemicelluloses began to measurably degrade after steaming for 60 min and both hemicelluloses and cellulose were considerably decreased after 720 min of heating at 180 °C. Gunduz et al. [12] showed that density, swelling and compression strength values decreased with increasing treatment temperature and treatment times. It was determined that the smallest decrease was observed in the treatment at 120 °C for 2 h. Kol [24] observed decreases of 13.1% and 9.5% in the MOE and 59.5 and 10.5% in the MOR of heat treated at 212 °C for pine and fir, respectively. In this study, the decrease in MOE was lower than MOR. Korkut [25] reported a decrease in MOE of 35% and in MOR of 16% at 180 °C for oven heat treated fir for 2 h. These changes were higher than our results though the same wood species was used.

According to the test results, the differences between the edge-wise and flat-wise MOR and MOR values were insignificant for all of the test samples. Consequently, the loading direction in the laminated structural elements was not generally influential in bending strength and modulus of elasticity.

4. Conclusion

The results showed that the density, swelling, flat-wise and edge-wise bending strength and modulus of elasticity of the LVL manufactured from heat treated poplar veneers decreased for all treatment. Higher weight decrease was obtained from the LVL with veneers treated at 180 °C. The highest decrement in the radial, tangential and longitudinal swelling was determined in the LVL made from veneers heat treated at 180 °C for 5 h. In the radial, tangential and longitudinal swelling, the values of LVL produced from untreated plies were higher than the values of LVL produced from heat treated plies.

The flat-wise and edge-wise MOE of LVL with veneers treated at 180 °C has lower values than other treatments. The highest increase in flat-wise and edge-wise MOE tests was determined at the LVL with untreated veneers. Based on the findings in this study, edge-wise bending strength and modulus of elasticity tested decreased with increasing in temperature and time.

The improved characteristics in swelling of LVL made from heat treated plies have to be balanced against the decrease in strength values when evaluating the effectiveness of using this treatment. Consequently, the evaluated results indicated that increase of the temperature and treatment time resulted in better dimension stability for the LVLs.

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