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Effect of Wood Species, Amount of Juvenile Wood and Heat Treatment on Mechanical and Physical Properties of Laminated Veneer Lumber

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Abstract: In this study, the effects of wood species, proportions of juvenile wood and heat treatment on the chemical composition, physical and mechanical properties of Laminated Veneer Lumber (LVL) were investigated. In this research, unheated and heated (at 120 and 180°C) juvenile, transitional and mature beech, maple and poplar veneers were used. The chemical composition of veneers was determined by gas chromatography. Statistical analysis of the data obtained from the tests showed that the wood carbohydrates were significantly degraded in the heated veneers. A direct relationship was found between physical and strength properties and hemicellulose losses of the LVL panels. As the hemicellulose contents in the veneers decreased, the losses in the swelling, water absorption, bending strength (MOR) and Modulus of Elasticity (MOE) of LVL increased. The effect of heat treatment on the mechanical properties was much more significant at the highest temperature (at 180°C) than at 120°C. Reduction of physical and mechanical properties in the LVL with juvenile wood was lower than those in specimens with mature veneer. Both juvenile wood and heat treatment considerably decreased in all investigated strength properties of LVL panels.

Key words: Laminated lumber board, heat treatment, juvenile wood, bending strength

INTRODUCTION

The mechanical and physical properties of LVL are affected by many factors such as wood species, veneer thickness and quality, processing variables and member size (Hing *et al*., 2001). Heat treatment is one of the processes used to modify the properties of wood (Mazela *et al*., 2004).

Theoretically, the available OH groups in hemicellulose have the most significant effect on the physical properties of wood. Heat treatment slows water uptake and wood cell wall absorbs less water because of the decrease of the amount of wood's hydroxyl groups. As a consequence of the reduced number of hydroxyl groups the swelling and shrinking are lower (Gunduz *et al*., 2008).

Chemical changes and structural modifications in the cell wall during heating have been reported to play a significant role in hydrophobicity of wood (Hakkou *et al*., 2005; Repellin and guynooet, 2005). The reduced hygroscopicity of heat-treated wood is often related to the degradation of hemicelluloses that occurs during the thermal treatment. Because the hemicelluloses are composed of shorter molecule chains and have a more branched structure, they are generally sensitive to thermal degradation.

Previous studies showed that shrinkage-swelling, strength, hardnessand density of wood decreased with heat treatment, while using this treatment also improved its dimensional stability (Yildiz, 2002). In similar investigation, an increased dimensional stability was obtained when temperature went up and as the duration increased (Rafidah *et al*., 2010).

It is well known that the juvenile wood is typical of the inner 10-18 growth rings and it can have an impact on stability and mechanical properties. In addition to lower density, juvenile wood has wider growth rings, shorter wood cells, higher longitudinal shrinking and increased spiral grain. Low wood density, numerous knotsand possibly a high proportion of juvenile wood appear to be major factors contributing to low veneer stress grading, resulting in a production of low-quality veneer (Zhang *et al*., 2004). Mechanical properties, such as shear strength and compression perpendicular to the grain (Kretschmann, 1997) have been shown to be decreased significantly with increasing juvenile wood content.

Efficient usage of LVL in the construction industry requires an understanding of the structural behavior of numerous species and knowledge about the effects of the heat treatment process and wood quality on the chemical, physical and mechanical properties of LVL. Therefore, the

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aims of this study were put forward to the effects of heat treatment veneer, wood species and amount of juvenile wood on the properties of LVL.

MATERIALS AND METHODS

We used beech (*F. orientalis*), maple (*A. insigne*) and poplar (*P. nigra*), three hardwood species growing in the north of Iran. The beech, maple and poplar materials were 20-30, 30-40 and 15-25 year-old trees, respectively. The ages that would best represent the beginning and end of the transition to mature material would be 12 and 18 years for beech and maple and 8 and 12 years for poplar. All stages of this study carried out at the Department of Wood and Paper Science and Technology, University of Zabol (Iran), from end of the autumn 2009 to beginning of the autumn 2010.

Round logs were cut into stocks in rough sizes. Samples (veneers) of these stocks, with dimensions of 9×150×360 mm, were prepared and were sanded in a belt-sanding machine, so that the finished sample thickness of 7 mm was obtained. The layers were divided into three categories based on the annual growth rings: an outer mature zone, a transitional zone and a juvenile core.

Some of the layers were subjected to heat treatment at 120 or 180°C for 4 h in a small heating unit controlled within ±1°C under atmospheric pressure. Heated and unheated layers were conditioned to 12% Moisture Contents (MC) in a conditioning room at 23°C and with 65% (±5) Relative Humidity (RH).

Three-layer LVL panels with 20 mm thickness were manufactured from the veneer sheets. About 180 g m^{-2} adhesive mixture of Urea Formaldehyde (UF) having 55% solid content was applied on single bonding surfaces of layers. Each panel was hot pressed at 12 kg cm^{-2} for approximately 8 min at a platen temperature of 120°C. After hot pressing, panels were allowed to cool for 24 hand then trimmed. These specimens were conditioned at 23°C and 65% RH (12% EMC) for several weeks.

Density, water absorption, thickness, tangential and longitudinal swelling, edgewise and flatwise MOR and MOE were tested. The bending properties were evaluated using a computer-controlled Hounsfield testing machine (modelH25KS) located at the University of Zabol.

About 5 to7 specimens, 30 mm long by 20 mm wide by 20 mm thick, were used to determine the density of each board type. The air-dry density was computed based on the air-dry weights located in air-dry condition. For swelling and water absorption tests, average sample size used was 100 mm long by 100 mm wide by 20 mm thick. The specimens were submerged in such a way that the top face of each specimen was about 2.5-3.0 cm from the surface of the water. After 2 h, the specimens were removed; extra water at the surface was wiped off with tissue paper and measurements were taken of weight and dimensions. After 24 h, the same procedure was repeated and samples were in the air for 15 h before oven drying. After oven drying, thickness and weight measurements were once again repeated quickly. According to ASTM D 1037 (1999) thickness, tangential and longitudinal swellings were calculated as a percentage. Similarly, Water Absorption (WA) in percentage was computed after 2 and 24 h of dipping in water. Six replicates were taken for each type of board.

Bending strength and modulus of elasticity tests were carried out with 6 samples with dimensions of 360×20×20 mm cut from each manufactured panel and the crosshead loading speed was kept at 1 mm min^{-1}. Therefore, based on the above mentioned variables, 27 kinds of boards (360×150×20 mm) were manufactured, with 3 alternatives of each type resulting in 81 boards in total. In order to conduct this test, guidelines were taken from ASTM D 5456-06 (2006) with a slightly smaller span-to-depth ratio of 15. Chemical analysis determined glucose, xylose, manose, arabinose and galactose contents, which are the five main sugars in wood that define the chemical composition of cellulose and hemicellulose. The standard methodology T-249 cm 85 from the Technical Association of Pulp and Paper Industry (TAPPI, 1985) was used in these analysis, using gas chromatography. The chromatographer used was the HP located at Laboratory of Bio- center at the University of Zabol.

The experimental results were statistically analyzed using multiple variance analysisand significant differences between the control and the treated samples were determined using Duncan's Multiple Range Test (ASTM D 3110-72, 1974).

RESULTS AND DISCUSSION

Chemical analysis: The chemical composition of unheated and heated veneers is given in Table 1. The decrease rates for arabinose, galactose and mannose at 180°C heated veneers when compared to untreated veneers are remarkable. Arabinose, mannose, galactose and xylose, which are responsible for hemicelluloses formation (Rowell *et al.*, 2005), were significantly influenced by increasing temperatures. For beech mature veneer, a reduction in the sum of their contents was observed from 71.30% in the original veneer to 65.45% in veneer treated at 180°C. For maple and poplar mature veneer, these values decreased from 65.47 and 67.0% to

Table 1: Sugar content of juvenile, transitional and mature beech, maple and poplar untreated veneers and heat treated at 120 and 180°C

	Temperature (°C)									
	Juvenile			Transitional			Mature			
Species (%)	Untreated	120	80	Untreated	120	80	Untreated	120	80	F-value
Beech										
Glucose	58.2±0.041a	57.7±0.23b	56.1±0.6c	53.60±0.44a	52.04±0.21b	48.64±38c	48.53±0.43a	46.99±0.39b	45.27±0.5c	52.7*
Xylose	26.63±0.17a	26.29±0.16b	23.77±0.27c	19.15±0.20a	18.47±0.43b	17.52±0.41c	18.10±0.66a	19.01±0.38b	16.81±0.05c	375.3*
Mannose	5.60±0.58a	4.82±0.34b	3.16±0.1c	4.01±0.2a	3.80±0.21b	2.59±0.21c	3.04±0.8a	2.79±0.21b	2.08±0.12c	312.5*
Gallactose	2.23±0.1a	1.94±0.06b	0.88±0.1c	1.44±0.11a	1.35±0.11b	1.00±0.02c	1.09±0.02a	1.05±0.14b	0.84±0.02c	256*
Arabinose	0.93±0.04a	0.90±0.12b	0.56±0.09c	0.64±0.07a	0.69±0.08b	0.48±0.03c	0.54±0.05a	0.51±0.02b	0.45±0.03c	345*
Maple										
Glucose	55.95±0.07a	55.17±0.61b	53.76±0.78c	52.14±0.78a	51.13±35b	47.68±0.16c	45.55±0.37a	43.30±0.37b	41.12±0.50c	52.7*
Xylose	20.93±0.33a	20.57±0.41b	17.64±0.46c	21.41±0.16a	21.59±0.27b	19.75±0.29c	15.33±0.17a	14.26±0.64b	13.40±0.25c	75.3*
Mannose	6.22±0.2a	6.01±0.12b	4.53±0.68c	2.94±0.05a	2.73±0.15b	2.23±0.15c	2.44±0.11a	2.22±0.1b	1.86±0.1c	312.5*
Gallactose	3.12±0.08a	3.06±0.04b	1.96±0.07c	2.44±0.1a	2.32±0.1b	1.96±0.07c	2.12±0.08a	2.09±0.11b	1.81±0.05c	256*
Arabinose	0.04±0.04a	0.06±0.06b	0.03±0.3c	0.04±0.04a	0.05±0.06b	0.02±0.05c	0.03±0.02a	0.04±0.08b	0.04±0.05c	345*
Popler										
Glucose	59.44±0.21a	57.93±0.24b	54.48±0.45c	55.33±0.30a	54.74±0.08a	50.43±0.54b	48.31±0.58a	46.22±0.65b	44.29±0.56c	52.7*
Xylose	19.06±0.35a	18.45±0.59b	15.04±0.76c	14.18±0.06a	12.82±0.56b	11.84±0.19c	14.86±0.31a	14.15±0.32	12.49±0.21	375.3*
Mannose	7.29±0.16a	6.04±0.34b	5.23±0.15c	3.17±0.16a	3.19±0.22b	2.27±0.16c	2.62±0.16a	2.66±0.12b	2.02±0.12c	312.5*
Gallactose	5.96±0.16a	6.14±0.15b	4.88±0.28c	4.32±0.12a	3.94±0.07b	2.61±0.05c	1.20±0.14a	1.11±0.1b	0.88±0.1c	256*
Arabinose	0.16±0.1a	0.12±0.07b	0.10±0.04c	0.05±0.09a	0.09±0.03b	0.07±0.06c	0.06±0.07a	0.11±0.03b	0.10±0.09c	345*

*Significant at 5% probability (Duncan, α = 5%). The letters in the same column represent statistical differences at a 95% confidence level (p≤0.05)

58.22 and 59.78%, respectively. For juvenile veneers, these values decreased from 93.59, 86.26 and 91.87% to 84.45 and 77.92 and 79.78%, respectively. This finding supports previous research that heat treatment causes important degradations of the material, resulting in a decrease of the hemicellulose content (Yildiz *et al*., 2006; Sweet and Winandy, 1999). Sweet and Winandy (1999) found that the arabinose, galactose, xylose and mannose content of southern pine dried at 66°C for 560 days decreased about 50% or more compared with that of untreated wood. A study by Yilgor *et al*. (2001) showed that the steaming of beech wood at 80°C for 20 and 100 h caused small decreases in hemicelluloses. The decrease rates for arabinose, galactose, rhamnoseand mannose in wood steamed for 100 h compared with untreated wood were 9.26, 7.69, 7.69 and 4.84%, respectively. LeVan and Winandy (1990) stated that the degradation of hemicelluloses and alpha-cellulose most closely follows that of the wood degradation; thus, the lower degradation temperature of wood compared to the lignin degradation temperature is due to the hemicellulose in the wood.

In the specimens exposed to heat treatment at 180°C, all glucose was degraded and the arabinose content of the same specimens decreased for the heat treated veneers, in comparison to untreated veneers. In the mature veneers heated at 180°C, manose, xylose and gallactose were the least affected hemicellulose types and second to the juvenile heated veneers at the same temperature.

Physical properties: The mean values of dimensional stability: thickness, tangential and longitudinal swelling (RS, TS and LS) and Water Absorption (WA) of LVL made of mature, transitional and juvenile veneers non-heat treated and heat treated at 120 and 180°C are listed in Table 2 and the results of the analysis of variance related to these physical properties are given in Table 3. The interaction between different factors was statistically identical ($p\leq 0.05$). The mean values of the variation sources that were found to be significant were compared using Duncan's test and the results are summarized in Table 4.

According to the results obtained in this study, all properties of LVL decreased by increasing temperature and this change was the greatest in 180°C (Table 2). The values of the physical properties of beech LVL panels were higher than those obtained for maple and poplar LVL. Great differences were found in mean density values of different LVLs.

The result of multiple variance analysis also proved that the effect of wood species, heat treatment and amount of juvenile wood on density, RS, TS, LS and WA was significant as shown in Table 3.

Table 2: Average swelling and water absorption of LVL

Wood type	Species	Temperature (°C)	Mean density (g cm^{-3})	RS_2 (%)	RS_{24} (%)	TS (%)	LS (%)	WA_2 (%)	WA_{24} (%)
Juvenile	Beech	0	0.64	20.3	28.9	15.7	1.84	13.67	26.17
		120	0.63	17.7	20.7	14.7	1.60	13.67	26.50
		180	0.60	14.9	17.0	9.6	1.14	9.00	18.5
	Maple	0	0.60	18.9	26.4	14.5	1.73	14.83	27.17
		120	0.58	18.2	26.9	13.6	1.37	14.33	27.17
		180	0.57	14.9	16.6	7.5	1.00	9.17	17.67
	Poplar	0	0.36	13.0	21.2	10.2	0.98	17.83	34.17
		120	0.35	11.4	19.6	8.7	0.85	15.67	31.00
		180	0.32	9.0	13.0	7.2	0.60	12.50	23.00
Transitional	Beech	0	0.65	18.0	27.8	11.7	1.15	11.33	20.67
		120	0.64	15.5	24.4	9.9	0.92	11.83	22.00
		180	0.62	11.5	19.8	7.1	0.93	9.17	18.00
	Maple	0	0.61	15.9	25.5	11.0	1.04	13.50	25.83
		120	0.60	14.8	23.7	9.6	0.93	12.50	22.83
		180	0.58	11.5	15.6	8.1	0.74	8.67	17.00
	Poplar	0	0.36	11.2	19.5	9.7	0.81	15.00	29.50
		120	0.37	10.4	19.4	6.1	0.77	14.50	28.33
		180	0.36	8.35	10.8	6.1	0.53	11.17	21.67
Mature	Beech	0	0.65	15.8	25.2	8.8	0.91	8.50	16.33
		120	0.66	13.7	22.7	7.5	0.8	7.83	14.5
		180	0.64	9.9	10.2	4.8	0.67	5.33	10.17
	Maple	0	0.62	12.6	22.5	7.9	0.88	7.50	16.33
		120	0.62	12.4	20.3	7.6	0.8	6.33	13.33
		180	0.6.0	10.2	13	5.6	0.57	4.50	9.33
	Poplar	0	0.37	9.1	18.2	7.5	0.63	11.5	21.50
		120	0.37	8.2	17.2	5.9	0.62	11.6	21.50
		180	0.36	6.6	10	3.6	0.34	8.50	16.50

RS_2: Thickness swelling after 2 h; RS_{24}: Thickness swelling after 24 h; TS: Tangential swelling; LS: Longitudinal swelling; WA_2: Water absorption after 2 h; WA_{24}: Water absorption after 24 h

Table 3: Statistical analysis of the tests

Parel properties	Source of variation	F-ratio	Significance level
MOR_v	Type of wood	915.5	p≤0.001
	Wood species	242.2	p≤0.001
	Temperature (°C)	1822.5	p≤0.001
MOR_p	Type of wood	732.1	p≤0.001
	Wood species	246.8	p≤0.001
	Temperature (°C)	1359.2	p≤0.001
MOE_v	Type of wood	1685.7	p≤0.001
	Wood species	2123.8	p≤0.001
	Temperature (°C)	502.4	p≤0.001
MOE_p	Type of wood	1245.7	p≤0.001
	Wood species	1754.2	p≤0.001
	Temperature (°C)	899.1	p≤0.001
Density	Type of wood	462.9	p≤0.001
	Wood species	935.4	p≤0.001
	Temperature (°C)	574.3	p≤0.001
RS_2	Type of wood	287.7	p≤0.001
	Wood species	520.8	p≤0.001
	Temperature (°C)	268.8	p≤0.001
RS_{24}	Type of wood	65.7	p≤0.001
	Wood species	152.8	p≤0.001
	Temperature (°C)	493.9	p≤0.001
TS	Type of wood	450.8	p≤0.001
	Wood species	167.8	p≤0.001
	Temperature (°C)	360.8	p≤0.001
LS	Type of wood	375.1	p≤0.001
	Wood species	239.4	p≤0.001
	Temperature (°C)	183.5	p≤0.001
WA_2	Type of wood	453.5	p≤0.001
	Wood species	173.9	p≤0.001
	Temperature (°C)	272.6	p≤0.001
WA24	Type of wood	291	p≤0.001
	Wood species	119.1	p≤0.001
	Temperature (°C)	162	p≤0.001

Table 2 shows that the beech, maple and poplar LVL groups had higher density values than those of solid wood from which LVLs were produced. The reason for higher density of LVL is related to the thickness loss of the panel due to the compression rate during hot pressing and the higher density of adhesive being used in panel production. It has been observed in several studies that heat treatment causes significant mass loss, resulting in a decrease of the hemicellulose content (Yildiz *et al*., 2006; Inari *et al*., 2007). Inari *et al*. (2007) studied heat treatment of beech and pine and observed that holocellulose content determined before heat treatment was approximately 75% for both species, while the values determined after heat treatment were between 50 and 60%. Brito *et al*. (2008) studied heat treatment of eucalyptus and pinus and observed an increase of mass loss at higher temperatures.

The density values of LVL groups decreased after the heat treatment of veneers. The reason for the density losses was the weight losses of veneers, occurring in the heat treatment. Most decreases in density values of LVL were observed when beech, maple and poplar juvenile veneers were treated at 180°C (0.32 gcm^{-3}). The density values of LVL panels with untreated mature beech veneers were higher compared to maple and poplar LVL.

LVL samples made from mature poplar veneers heated at 180°C have shown the lowest RS, TS and LS (6.6, 3.6

Table 4: Duncan test results of LVL ($p \leq 0.05$)*

Source of variance	Density (g com^{-3})	RS_2 (%)	RS_{24} (%)	TS (%)	LS (%)	WA_2 (%)	WA_{24} (%)
Wood type							
Juvenile	0.522a	15.39c	21.16b	11.31c	1.23c	13.35c	25.70c
Transitional	0.534b	13.03b	20.16b	8.86 b	0.87b	11.96b	22.87b
Mature	0.543c	10.94a	17.7 a	6.58 a	0.69a	7.93a	15.50a
Species							
Poplar	0.359a	9.7 a	16.58a	2.28a	0.68a	13.9 b	25.24b
Maple	0.601b	14.4b	21.16b	9.5 b	1.0 b	10.14a	19.62a
Beech	0.639c	15.27c	21.86c	9.98c	1.1 c	10.03a	19.20a
Temperature (°C)							
180	0.52 a	10.78a	14a	6.61a	0.72a	8.6a	16.82a
120	0.537b	13.59b	21.67b	9.36b	0.96b	12.04b	23.01b
0	0.543c	15 c	23.92c	10.78c	1.1 c	12.62b	24.18c

The letters in the same column represent statistical differences at a 95% confidence level ($p \leq 0.05$); MOR: Modulus of Rupture; MOE: Modulus of Elasticity; v: Vertical to the glue line; p: Parallel to the glue line

Table 5: Average bending strength and modulus of elasticity of LVL

Wood Type	Species	Temperature (°C)	MOR_v	MOR_p (MPa)	MOE_v	MOE_p
Juvenile	Beech	0	45.5	36.7	6604	7206
		120	39.7	32	6186	5729
		180	24.8	19.8	5668	4952
	Maple	0	44.7	36.3	6489	6936
		120	38.1	30.6	6140	5675
		180	24.3	18.2	5645	5126
	Poplar	0	39.1	30.7	4025	3759
		120	29.7	24.1	3076	2811
		180	22.8	17.3	2585	2191
Transitional	Beech	0	73.2	67.7	11340	10937
		120	51.0	44.6	11063	10735
		180	30.8	25.9	9651	7313
	Maple	0	72.3	66.6	11055	10857
		120	43.8	37.7	10652	10370
		180	30.1	24.2	9690	6598
	Poplar	0	50.5	42.5	6427	6104
		120	39.3	34.7	5768	5446
		180	25.0	18.8	4112	2901
Mature	Beech	0	86.0	82.3	12891	12967
		120	62.1	61.3	12541	12276
		180	39.3	34.1	7723	7069
	Maple	0	81.7	70.8	12818	12815
		120	61.8	56.8	10574	10278
		180	40.0	34.9	8678	8322
	Poplar	0	65.0	59.0	6964	6700
		120	55.0	48.1	6967	6690
		180	25.7	10.8	3601	3153

MOR: Modulus of Rupture; MOE: Modulus of Elasticity; v: Vertical to the glue line; p: Parallel to the glue line

Table 6: Duncan test results of LVL ($p \leq 0.05$)*

Source of variance	Mpa			
	MOR_v	MOR_p	MOE_v	MOE_p
Type of wood				
Juvenile	34.2a	27.3a	5158a	4932a
Transitional	46.2b	40.3b	8862b	7918b
Mature	57.4c	50.9c	9195c	8919c
Wood species				
Poplar	39.1a	31.8a	4836a	4417a
Maple	48.5b	41.8b	9082b	8553b
Beech	50 c	44.9c	9296c	8798c
Temperature (°C)				
180	29.2a	22.6a	6373a	5292a
120	46.7b	41.1b	8107b	7779b
0	62.0c	54.7c	8735c	8698c

*The letters in the same column represent statistical differences at a 95% confidence level ($p \leq 0.05$); MOR: Modulus of Rupture; MOE: Modulus of Elasticity; v: Vertical to the glue line; p: Parallel to the glue line

and 0.34%) after 2 h of water immersion, while LVL made of beech juvenile unheated veneer has shown the highest value (20.3, 15.7 and 1.84%) after 2 h of dipping. After 2 h of dipping, minimum value of water absorption was obtained with LVL panels made of beech mature veneers heated at 180°C compared to maple and poplar LVL. After 2 and 24 h, the LVL made of untreated juvenile poplar veneer had maximum value of water absorption in the range of 16-18 and 34-37%, respectively.

In addition, compression wood and spiral grain are both more prevalent in juvenile wood than in mature wood. The excessively high micro-fibril angle in juvenile wood causes excessive longitudinal swelling and shrinkage that may be more than 10 times that of mature wood.

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 (Dirol and Guyonnet, 1993). In this study, the decrease rates for arabinose, gallactose, xyloseand mannose (Table 1) in heated veneers compared to unheated veneers indicated that the high temperature decreases the equilibrium moisture of veneer and consequently the swelling of panels made of veneers.

Mechanical properties: The mean values of bending strength and modulus of elasticity of LVL panels are given in Table 5. The multi variance analysis related to the bending strength (MOR) and Modulus of Elasticity (MOE) of LVL samples after the veneers were exposed to heat are also given in Table 3. The differences among the groups regarding the effect of variance sources on flatwise and edgewise MOR and MOE are significant. The DUNCAN test results used to determine the importance of the differences among the groups are given in Table 6.

Table 5 shows that heating has an adverse effect on the strength properties of LVL panels through its effect on chemical composition. The highest edgewise and flatwise MOR was obtained in mature untreated beech LVL samples (82.3 and 86 MPa). The flatwise MOR of LVL made of beech, maple and poplar juvenile veneers treated at 180°C decreased (24.8, 24.3 and 22.8 MPa), compared with those properties of untreated LVL panels (45.5, 44.7 and 39.1 MPa). Bending strength decreased 43-83% and modulus of elasticity decreased 41-53, compared to those properties of LVL with untreated mature veneer (Table 5). The lowest edgewise bending strengths for LVLs with juvenile beech, maple and poplar veneer were observed when the veneers heated at 180°C (19.8, 18.2 and 17.3 MPa). The decrease was between 47 and 58% for LVLs with beech veneers, between 49 and 51% for LVLs with maple veneersand between 43 and 83% for LVLs with poplar veneers, treated at 180°C. Similar results have been observed in several previous studies that heat treatment causes decrease in mechanical properties of the wood and wood composite material. In fact, the mechanism of strength loss during heat treatment is related to progressive degradation of hemicelluloses between microfibrils (Sweet and Winandy, 1999; Yilgor *et al*., 2001). A study by Yilgor *et al*. (2001) showed that the percent reductions in strength losses in the steamed beech wood were greater than the percent reductions in hemicellulose losses compared with the results of previous studies (LeVan and Winandy,1990; Sweet and Winandy, 1999; Sweet, 1995) and agreed that the hemicellulose loss in thermally degraded wood correlated with strength loss.

Strength loss of LVL with poplar juvenile veneer treated at 180°C was greatest for MOEv and MOEp (2 191 and 2 585 MPa). The highest flatwise and edgewise MOE was obtained in beech mature untreated LVL samples (12 891 and 12 967 MPa). These studies agree that hemicellulose loss in thermally degraded wood and proportion of juvenile wood are correlated with strength loss. Arabinose, manose, galactose and xylose, which are responsible for hemicelluloses formation, were significantly influenced by increasing temperatures. For poplar veneer, a reduction in the sum of their contents was observed from 79.8% in the treated juvenile veneer to 59.8% in the mature treated veneer (Table 1). For beech and maple LVL, these values decreased from 84.45 to 65.45% and from 77.76 to 58.23%, respectively.

The flatwise MOR of LVL panels manufactured from beech veneers were higher than those manufactured from maple and poplar veneers. One of the reasons for this can be the higher density of beech wood compared to maple and poplar woods.

Lumber cut off the juvenile wood zone of logs has the potential to be significantly lower in strength than does lumber from the mature wood zone; the magnitude of reductions varies by species. Properties that influence mechanical behavior include fibril angle, cell length, specific gravity, cell wall thicknessand lumen diameter. The excessively high micro-fibril angle in juvenile wood causes excessive strength loss. Both compression wood and spiral grain are more prevalent in juvenile wood than in mature wood also they contribute to excessive strength loss in LVL. In this case, similar results have been observed in previous studies. Kretschmann *et al*. (1993) studied effect of various proportions of juvenile wood on properties of laminated veneer lumber and showed that a significant difference exists between materials manufactured with mature or juvenile material having the same nondestructive grade. In this study, both Southern Pine and Douglas-fir LVL showed a predictable decrease in strength and stiffness with increased juvenile wood content. The ratio of juvenile to mature material with the same nondestructive grade was approximately 0.8 for strength and stiffness. Roos *et al*. (1994) showed that compaction ratios average 1.63 for the juvenile aspen wood panels and 1.38 for the mature aspen wood panels has significant effect on properties of flakeboard panels and concluded that the strengths are affected by increasing compaction ratio. But, juvenile wood is distinctly of poorer quality than mature wood. Properties that influence mechanical behavior include high micro-fibril angle, compression wood and spiral grain, cell length, specific gravity, cell wall thickness and lumen diameter. This abnormal structure of juvenile wood decreases the mechanical properties and increases WA and TS of LVL panels.

In general, the results of this study on the effect of heat treatment and proportion juvenile wood on LVL are compatible with the findings in the literature on the effect of heat treatment and juvenile wood on different LVLs.

The results showed poplar, maple and beech LVL tests for bending strength and modulus of elasticity either flatwise or edgewise seem to be greatly influenced by densities of panels. The values decreased with the decreases in density of LVL. A reduction in density was observed for poplar panels from 3% in the mature treated wood to 6% in the juvenile heat treated wood (Table 2). For beech and maple, these values increased from 3% to 6 and 3 to 5%, respectively.

CONCLUSION

The influence of wood species and juvenile wood on the chemical, physical and strength properties of LVL made with untreated veneers and heated at temperatures of 120 and 180°C were evaluated. The results showed that arabinose, manose, galactose and xylose contents of wood decreased significantly compared to original wood.

Both beech and maple and poplar LVL samples had higher density values than those of solid wood from which LVLs were produced. After the heating process, similar results were found.

The highest values of radial, tangential and longitudinal swelling were determined in LVL samples with untreated veneers. The highest and lowest radial, tangential and longitudinal swelling were determined in LVL with juvenile untreated beech veneer and mature poplar veneer treated at 180°C, respectively.

Bending strength and modulus of elasticity values parallel and vertical to the glue line of samples were found to be lower for LVL with juvenile veneers heated at 180°C than those of LVLs produced of the mature untreated veneers. According to the results obtained in this study, heat treatment of veneers alters the physical and chemical properties significantly, but the strength properties begin to deteriorate.

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