THE EFFECTS OF WOOD SPECIES, LOAD DIRECTION, AND ADHESIVES ON BENDING PROPERTIES OF LAMINATED VENEER LUMBER

Bekir Cihad Bal* and İbrahim Bektaş

In this study, the bending strength and stiffness of laminated veneer lumber (LVL) produced from beech (*Fagus orientalis* L.), poplar (*Populus x euramericana* I-214), and eucalyptus (*Eucalyptus grandis* W. Hill ex Maiden) wood using urea formaldehyde (UF), melamine urea formaldehyde (MUF), and phenol formaldehyde (PF) adhesives were determined. The tests were conducted in the flatwise and edgewise directions. The modulus of rupture (MOR), modulus of elasticity (MOE), specific modulus of rupture (SMOR), and specific modulus of elasticity (SMOE) were calculated. Variance analysis of the bending properties indicated that the effects of the species of tree, the direction of the load, and the type of adhesive were statistically significant. However, according to variance analysis of the SMOR, the effects of the type of adhesive were not significant. The results showed that the type of adhesive did not influence the bending properties of laminated veneer lumber. It can be stated that the differences among groups were due to differences in their densities. The direction of the load and the species of the tree had significant effects on the bending properties.

Keywords: Laminated veneer lumber (LVL); Bending properties; Type of adhesive; Direction of the load; Eucalyptus grandis; Mechanical properties

*Contact information: Faculty of forestry, Kahramanmaraş Sütçü İmam University, 46060, K.maraş/Turkey; * Corresponding author: bcbal@ksu.edu.tr, bcbal@hotmail.com*

INTRODUCTION

Eucalyptus grandis is a fast-growing tree species, and interest in this species increases day by day. While it is planted in industrial plantations in regions that have hot climates, such fast-growing species of trees have some undesirable properties. Relevant to this topic, Kojima *et al*. (2009) wrote that "because of the short rotations, there is concern that fast-growing species would contain a large volume of juvenile wood bearing unstable properties. This concern is an obstacle for the use of fast-growing species for timber."

LVL (laminated veneer lumber) is structural composite lumber and is used in wooden buildings. LVL is similar to plywood and is produced in larger quantities than other structural composite lumber (Berglund and Rowell 2005). LVL products are used for new residential construction; non-residential construction, including schools, restaurants, stores, and warehouses; and the repair and remodeling of homes (Anon. 2009).

In general, LVL is manufactured from softwood species and low- to medium-density (290 to 693 kg/m^3) hardwood species of trees. *Populus tremuloides*, *Populus balsmifera*, *Liriodendron tulipifera*, *Acacia mangium*, *Gmelina arborea*, *Albizia falcata*, and some eucalyptus species have been used or tested for use in the manufacture of LVL (Ozarska 1999). Saviana *et al*. (2009) determined the bending properties of structural LVL made of Argentinian *Eucalyptus grandis*. The modulus of rupture, modulus of elasticity, and density were determined to be 70.6 N/mm^2, 17147 N/mm^2, and 753 kg/m^3, respectively.

In Turkey, various species of hardwood trees, *e.g.*, poplar, hybrid poplar (*Populus deltoides, Populus x euramericana*), and oriental beech (*Fagus orientalis* L.) are used extensively for manufacturing plywood. In addition, experimental studies have been conducted with some other tree species.

Kurt (2010) studied the suitability of three hybrid poplar clones for LVL manufacturing using MUF adhesives. Samples were tested in the flatwise direction, and the results showed that the *Populus deltoides* clones had better physical and mechanical properties than the *Populus x euramericana* clone. The modulus of rupture, modulus of elasticity, and the density of the oven-dried samples were determined to be 75.1 N/mm^2, 6305 N/mm^2, and 0.42 g/cm^3, respectively.

The modulus of rupture (MOR) and modulus of elasticity (MOE) are important mechanical properties for materials used in building construction. Extensive research has been conducted on the bending strength and stiffness of LVL produced from different species of trees. Wood density, press pressure, adhesives type, and load direction are crucial parameters for the bending strength and stiffness of LVL. In general, it has been noted that the MOR and MOE of LVL increase as the density of the wood increases (Shukla and Kamdem 2008; Saviana *et al*. 2009; Kurt 2010). In addition, Çolak *et al*. (2007) studied the effect of log steaming on the mechanical properties of LVL, and the results showed that all of the strength properties decreased significantly.

In some studies on wood-based panels, the differences in the density of the manufactured material influence the results to such an extent that they are not comparable. Regarding this issue, Bao *et al*. (2001) indicated that the effect of the density of composite materials also is evaluated often based on specific strength properties. Therefore, to eliminate the effect of density on the results, specific MOR (SMOR) and specific MOE (SMOE) also were calculated. In addition, Lee *et al*. (1999) calculated and compared SMOR and SMOE values of three different LVLs made of *Liriodendron tulipifera* L. veneers based on the test results and average specific density of each veneer-joint group.

Different results have been obtained in various research efforts concerning the effect of adhesives type on the bending strength and stiffness of LVL. In some of the research, it was noted that the type of adhesive affected MOR and MOE (Aydın *et al*. 2004; Çolak *et al*. 2004; Kılıç *et al*. 2006; Kılıç 2011). Conversely, Shukla and Kamkem (2009) conducted a study of the bending properties of LVL made of *Liriodendron tulipifera* and found that the adhesives had an insignificant effect.

In some research made on the effects of the direction of the load, it was determined that the bending strength and stiffness parallel to the direction of the glue line (edgewise) were greater than they were perpendicular to the direction of the glue line (flatwise) (Burdurlu *et al*. 2007; Kılıç 2011). However, in some other similar studies, just the opposite was observed (Wang and Dai 2005; Carvalho *et al*. 2004).

In this study, the following activities were conducted:

1. Determination of how the direction of the load and some formaldehyde-based adhesives affect the MOR and MOE of LVL produced from some hardwood species
2. Comparison of the values of MOR and MOE for LVL produced from eucalyptus, poplar, and beech woods
3. Measurement and comparison of SMOR and SMOE for various species of trees, types of adhesives, and load directions.

MATERIALS AND METHODS

Five beech and five poplar logs were obtained from the Yenice-Karabük region, and 30 eucalyptus logs were obtained from the Karabucak-Tarsus region. The diameters of the beech logs, poplar logs, and eucalyptus logs were about 60 cm, 50 cm, and 30 cm, respectively. The beech logs and eucalyptus logs were steamed at 80 ^{o}C for 50 and 15 hours, respectively. The poplar logs were not steamed. Then, 3 mm thick rotary-peeled veneers were obtained from the logs and dried in a plywood factory until the moisture content was 7±1%. The veneers were classified visually based on the sizes of the defects that were observed. Only grade 1 veneers were sorted visually according to TS 4893 based on the Turkish standards, and used to manufacture LVLs using UF, MUF, and PF adhesives. The formulation of the adhesives and the conditions used during the press operation are given in Table 1. Approximately 200 g/m^2 of the adhesives were spread manually on the loose side of the veneers using a gluing machine. After gluing, seven veneer sheets with a nominal size of 600 × 600 × 3 mm^3 (length × width × thickness) were laid with the fiber directions parallel to each other and pressed in a hot press in the laboratory. Experimental five panels were produced per groups. Panels were stored for a week after pressing, after which 30-mm edges were trimmed off of the panels.

Table 1. Formulation of Adhesives (units are parts by weight) and Press Conditions

Adhesives type	Adhesives amount	Wheat flour	Hardener ($(NH_4)_2SO_4$)	Press duration (min.)	Press pressure (kg/cm^2)	Press temperature (^{o}C)
UF	100	30	10	24	8 (for poplar)	110
MUF	100	15	10	24	12 (for beech)	110
PF	100	0	0	24	12 (for eucalyptus)	140

Equilibrium moisture content (EMC), values of air-dry density, MOR, and MOE were determined according to Turkish standards TS 2471, TS 2472, TS 2474, and TS 2478, respectively. After the samples were conditioned at 20±3 ^{o}C temperature and 65±5% relative humidity, flatwise and edgewise three-point flexural tests were performed on using samples that were 20 mm wide and 300 mm long. The thickness of the LVL was about 20 mm. As shown in Fig. 1, two test samples for density and moisture content were cut from each of the test samples after the bending strength test. Moisture content of the test samples were used to correct the strength values.

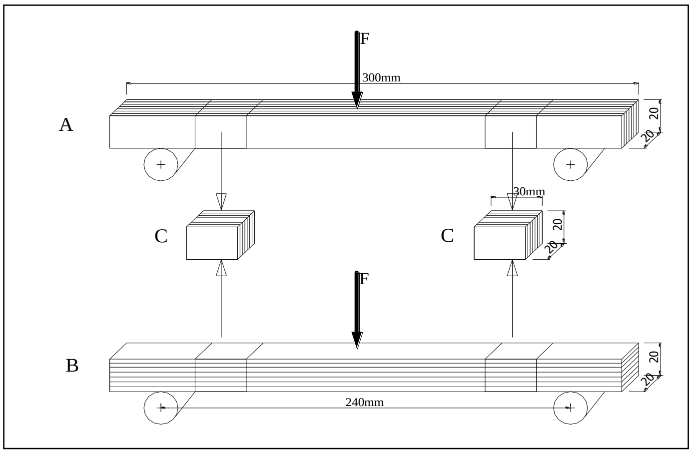

Fig. 1. (A) Edgewise and (B) flatwise bending strength test samples, and (C) density and moisture content test samples

Fifteen flatwise and edgewise test samples were cut from the same board. Before the test, the dimensions of the samples were measured to a precision of 0.01 mm. The data were analyzed using a three-way analysis of variance general linear model (three-way ANOVA), and significant differences among groups were determined by the Tukey Honestly Significant Difference (HSD) multiple range test. The SPSS statistical package program was used.

SMOR and SMOE were calculated using Equation (1). After the test, the moisture content of the samples was determined, and the strength values were corrected using the strength conversion Equation (2).

$$SMOR = \frac{MOR}{D_{12}} \text{ (km)}; \quad SMOE = \frac{MOE}{D_{12}} \text{ (km)}, \tag{1}$$

In this equation, SMOR, SMOE, MOR, and MOE are the specific modulus of rupture and specific modulus of elasticity, the modulus of rupture, and modulus of elasticity at 12% moisture content (N/mm^2), respectively. D_{12} is the air-dry density at 12% moisture content (kg/m^3),

$$\sigma_{12} = \sigma_M (1+\alpha (M - 12)) \tag{2}$$

where, σ_{12} is the strength at 12% moisture content, σ_M is the strength at M% moisture content, α is a constant (α = 0.04 for MOR and 0.02 for MOE), and M is the moisture content during the test.

RESULTS AND DISCUSSION

The mean values of air-dry density and Tukey comparison test results are given in Table 2. As shown, no differences were determined between poplar LVL groups. Similarly, no differences were determined between eucalyptus LVL groups. However, significant differences were determined for beech LVL groups bonded with UF, MUF, and PF adhesives ($P < 0.001$). The highest air-dry density was for beech LVL bonded with PF. It is likely that these differences related to the press temperature and veneer feature that was used in these groups.

Density is the most defining factor among the properties of wood and wood-based composites, and it is considered a good predictor of strength properties (Shulka and Kamdem 2008). In the present study, to eliminate the effect of density on SMOR and SMOE, they were calculated separately in all groups. In addition, ANOVA was conducted on the SMOR and SMOE groups.

Table 2. Air-Dry Density and Moisture Content of LVL Bonded With UF, MUF, and PF (n: 60)

		Poplar			Beech			Eucalyptus		
		UF	**MUF**	**PF**	**UF**	**MUF**	**PF**	**UF**	**MUF**	**PF**
Air-dry Density (kg/m^3)	**x**	447 **A**	444 **A**	449 **A**	664 **C**	654 **C**	680 **D**	636 **B**	627 **B**	638 **B**
	s	24.8	21.1	17.6	21.7	9.4	26.3	21.9	31.5	27.3
Equilibrium Moisture Content (%)	**x**	10.4	10.4	10.2	10.1	9.9	10.3	10.1	10.2	10.0
	s	0.35	0.5	0.25	0.25	0.2	0.1	0.2	0.35	0.2

x : mean values, s : standard deviation (α: 0.05)

According to Table 3, MOR and MOE values of the poplar LVL bonded with UF, MUF, and PF were less than those for the beech and eucalyptus LVLs, as expected. MOR and MOE values for eucalyptus and beech LVLs were similar. The highest MOR value was measured for beech LVL bonded with PF, and the highest MOE was measured for eucalyptus LVL bonded MUF in the flatwise direction. In general, MOR and MOE were determined to be high in the groups that had higher density values. It is known that there is a strong relationship between bending properties and the density of wood and veneer products.

Table 3. Mean Values of MOR, MOE, SMOR, and SMOE

			UF				MUF				PF			
			MOR (N/mm^2)	MOE (N/mm^2)	SMOR (km)	SMOE (km)	MOR (N/mm^2)	MOE (N/mm^2)	SMOR (km)	SMOE (km)	MOR (N/mm^2)	MOE (N/mm^2)	SMOR (km)	SMOE (km)
Eucalyptus	**Edge wise**	**x**	79,46	8584	12,79	1383	87,14	9257	13,81	1467	89,02	9047	14,20	1442
		s	6,96	418	0,91	66	6,89	525	1,18	81	6,07	488	0,79	40
	Flat wise	**x**	89,30	9131	13,99	1431	91,74	9649	14,58	1530	90,20	9189	14,00	1426
		s	8,13	520	1,23	73	9,88	1060	1,57	124	7,01	671	1,08	98
Poplar	**Edge wise**	**x**	62,35	6247	14,29	1432	59,88	6013	13,73	1379	60,33	5880	13,50	1315
		s	4,45	423	0,67	64	4,30	298	0,90	53	6,67	569	1,40	107
	Flat wise	**x**	68,14	6690	15,07	1480	69,76	6484	15,49	1440	69,49	6719	15,41	1489
		s	5,22	565	0,77	92	5,75	393	1,48	118	5,45	365	1,19	72
Beech	**Edge wise**	**x**	85,14	7877	13,11	1213	89,22	8194	13,69	1257	93,03	8302	13,85	1236
		s	7,39	693	0,82	77	4,17	352	0,45	38	6,17	478	0,57	36
	Flat wise	**x**	95,41	8773	14,10	1297	89,43	7948	13,63	1211	100,08	9087	14,51	1317
		s	8,33	701	1,13	94	2,16	420	0,33	67	10,14	587	1,51	84

x : mean values, s : standard deviation

The SMOR values were higher in the flatwise direction for poplar LVL than those of other groups. Similar results were determined by Bao *et al*. (2001) for specific MOR values of LVL made of the poplar 63 clone. In the present study, all groups had MOR, MOE, SMOR, and SMOE values that were higher in the flatwise direction than the values in the edgewise direction. These phenomena occur because of the effects of press pressure in the flatwise direction during the manufacturing process for LVL boards. Thus, linear density increases in the flatwise direction. These phenomena are valid in most wood-based panels produced by the hot-press process.

The test results of MOR, MOE, SMOR, and SMOE in the flatwise and edgewise directions are given in Table 3. The results of three-way ANOVA related to these properties and the Tukey multiple-range test results are given in Table 4 and 5, respectively.

Table 4 represents the results of three-way ANOVA related to the effect of tree species, load direction, and type of adhesive on MOR, MOE, SMOR, and SMOE. The results of ANOVA indicate that the differences among tree species and load direction had significant effects on the values of MOR, MOE, SMOR, and SMOE ($P < 0.001$). The effect of the type of adhesive on the MOR was significant with 0.001 error probability. But, the effect of the type of adhesive on the SMOR, MOE, and SMOE was insignificant. In this study, the values of SMOR and SMOE were determined to eliminate the effect of density on MOR and MOE. So, based on the results of ANOVA, it can be stated that the formaldehyde-based adhesives used in the study had insignificant effects on the values of MOR and MOE. In this regard, some researchers have noted that formaldehyde-based adhesives do have an effect on flexural properties, but some other researchers have concluded just the opposite. In fact, it has been reported that formaldehyde-based adhesives have effects in bonding tests, *i.e.*, they affect tensile-shear strength, internal bond strength, and block-shear strength in wet conditions and in certain service environments (Gillespie and River 1976; Shukla and Kamdem 2009).

Formaldehyde-based adhesives and cross-linked adhesives act differently in mechanical tests, and the type of adhesive may have a significant effect. In this regard, Shulka and Kamdem (2009) stated that "based on the nature of the adhesive, it is evident that LVL made with thermoplastic resin is less rigid and more plastic than LVL made with thermosetting adhesive."

Table 4. Three-way ANOVA Related to the Effect of Tree Species, Direction of the Load, and the Type of Adhesive on the Values of MOR, SMOR, MOE, and SMOE (α = 0.05)

	MOR		SMOR		MOE		SMOE	
Source of variation	**F value**	**Sig. Level**	**F value**	**Sig. Level**	**F value**	**Sig. Level**	**F value**	**Sig. Level**
Tree Species (TS)	426.1	0.000	14.2	0.000	608.3	0.000	149.8	0.000
Load Direction (LD)	62701	0.000	44.9	0.000	49	0.000	31.3	0.000
Adhesives Type (AT)	7269	0.001	2.6	0.072	1842	0.161	0.4	0.684
TS*LD	1318	0.269	5.5	0.004	0.9	0.403	3.9	0.020
TS*AT	4533	0.001	2.7	0.029	8799	0.000	7.8	0.000
LD*AT	1925	0.148	0.2	0.794	3965	0.020	2.5	0.080
TS*LD*AT	3269	0.012	3.7	0.005	3.9	0.004	5.7	0.000

Table 5. Tukey Multiple-Comparison Test Results Related to the Effect of Tree Species, Direction of the Load, and Type of Adhesive on the Values of MOR, MOE, SMOR, and SMOE

Tree Species

Source of variance	n	MOR (N/mm^2)	MOE (N/mm^2)	SMOR (km)	SMOE (km)
Poplar	90	64.9 A	6338 A	14.5 B	1422 B
Eucalyptus	90	87.8 B	8363 B	13.9 A	1446 B
Beech	90	92.0 C	9142 C	13.8 A	1255 A

Adhesives Type

Source of variance	n	MOR	MOE	SMOR	SMOE
UF	90	79.9 A	7883 A	13.9 A	1371 A
MUF	90	81.1 A	7924 A	14.1 A	1372 A
PF	90	83.6 B	8037 A	14.2 A	1380 A

Load Direction

Source of variance	n	MOR	MOE	SMOR	SMOE
Edgewise	135	78.3 A	7711 A	13.6 A	1347 A
Flatwise	135	84.8 B	8185 B	14.5 B	1402 B

Capital letter indicates significant difference by Tukey mean separation test.

Table 5 presents the results of the Tukey test related to the effects of tree species, direction of the load, and type of adhesive on the values of MOR, MOE, SMOR, and SMOE. Tree species affected the values of MOR, MOE, SMOR, and SMOE significantly. LVL made of poplar had the lowest MOR (64.9 N/mm^2) and MOE (6338 N/mm^2), while it had the highest SMOR (14.5 km). LVL made of beech had the highest MOR (92.0 N/mm^2) and MOE (9142 N/mm^2), while it had the lowest SMOR (13.8 km).

LVL bonded with UF had the lowest MOR, MOE, SMOR, and SMOE values, and LVL bonded with PF had the highest values. The type of adhesive had no significant effect on the values of MOR, MOE, and SMOR, with the exception of the MOR value of LVL that was bonded with PF. Apparently, these differences resulted from the density of this group, as verified by the SMOR values.

The effect of the direction of the load on the values of MOR, MOE, SMOR, and SMOE for the LVL groups was significant. The values of MOR, MOE, SMOR, and SMOE were determined to be 78.3 N/mm^2, 7711 N/mm^2, 13.6 km, and 1347 km in the edgewise direction, respectively, whereas they were determined to be 84.8 N/mm^2, 8185 N/mm^2, 14.5 km, and 1402 km in the flatwise direction, respectively. All of the results in the flatwise direction were greater than the corresponding values obtained for the edgewise direction. Similar results were determined by Carvalho *et al*. (2004) for MOR and MOE values of LVL made of a hybrid of *E. grandis* and *E. urophylla*. Wang and Dai (2005) also determined higher MOR and MOE values of LVL made of aspen veneers in the flatwise direction than those in the edgewise direction.

Regression analyses were carried out to find the relationships among MOE, MOR, and density. Thus, differences in the flatwise and edgewise direction of LVL produced poplar, beech, and eucalyptus were determined. Accordingly, Table 6 shows coefficients of determination (R^2) between MOE and MOR, MOE and density, and MOR and density in the edgewise and flatwise direction. The highest coefficient of determination was calculated from LVL made of beech in the edgewise direction (0.79) between MOE and MOR. The lowest coefficient of determination was calculated from LVL made of eucalyptus in the flatwise direction (0.03) between MOR and density. It is thought that the reason for this is surface roughness of eucalyptus veneers. On this subject, Aydın *et al*. (2004) stated that surface roughness has a negative effect on bonding strength of LVL made of *E. camaldulensis* veneers.

Table 6. Coefficients of Determination between MOE and MOR, MOE and Density, and MOR and Density in the Edgewise and Flatwise Directions

		MOE and MOR	MOE and Density	MOR and Density
	Edgewise	0.76	0.26	0.21
Poplar	Flatwise	0.44	0.10	0.08
	Edgewise	0.79	0.68	0.72
Beech	Flatwise	0.62	0.27	0.21
	Edgewise	0.49	0.39	0.21
Eucalyptus	Flatwise	0.33	0.22	0.03

The coefficients of determination were greater in the edgewise direction in all groups than they were in the flatwise direction. It was speculated that rupture occurred in the glue line during the tests. Therefore, as veneer density increases, the glue line breaks earlier in the flatwise tests than in the edgewise tests.

CONCLUSIONS

In this study, we determined the effects of tree species, type of adhesive, and direction of the load on the flexural properties and specific flexural properties of LVLs bonded with formaldehyde-based adhesives. In addition, LVLs produced from eucalyptus and poplar, which are fast-growing tree species, were compared with LVL made from beech. The results showed that:

- The highest flexural properties were found for LVL groups manufactured from beech veneer and bonded with PF adhesives. The flexural properties of LVL obtained from eucalyptus were comparable to those of LVL from beech veneer even though eucalyptus is a very fast-growing tree species.
- The highest SMOR values were calculated for LVL made of poplar. The SMOR values of beech and eucalyptus were similar. SMOR may be a good predictor value in research related to some mechanical properties.
- The effect of adhesives on MOE was determined to be insignificant. However, their effect on MOR was significant, but the effect was found to be related to density by SMOR.
- The MOR, MOE, SMOR, and SMOE values in the flatwise direction were significantly greater than those in the edgewise direction.
- The coefficients of determination between MOE and MOR, MOE and density, and MOR and density were determined to be greater in the edgewise direction in all groups than those in the flatwise direction.

ACKNOWLEDGEMENT

The authors thank the Research Fund of Kahramanmaraş Sütçü İmam University for financial support of this study (Project No: 2009/3-2D).

REFERENCES CITED

Anonymous. (2009). *Forest Products Annual Market Rewiev*, Food and Agriculture Organization of the United Nations. P:139–143 Geneva- Switzerland.

Aydın, İ., Çolak, S., Çolakoğlu, G., and Salih, E. (2004). "A comparative study on some physical and mechanical properties of laminated veneer lumber (LVL) produced from beech (*Fagus orientalis* l.) and eucalyptus (*Eucalyptus camaldulensis* dehn.) veneers," *Holz Roh Werkst.* 62, 218-220.

Bao, F., Fu, F., Choong, E. T., and Hse, C. (2001). "Contribution factor of wood properties of three poplar clones to strength of laminated veneer lumber," *Wood Fiber Sci.* 33(3), 345-352.

Berglund, L., and Rowell, R. M. (2005). *Wood Composites, Handbook of Wood Chemistry and Wood Composites*, CRC Press, pp. 290-291

Burdurlu, E., Kılıç, M., Ilce, A. C., and Uzunkavak O. (2007). "The effects of ply organization and loading direction on bending strength and modulus of elasticity in laminated veneer lumber (LVL) obtained from beech (*Fagus orientalis* L.) and Lombardy poplar (*Populus nigra* L.)," *Constr. Build Mater.* 21, 1720-1725.

Carvalho, A. M., Lahr, F. A. R., and Bortoletto, G. (2004). "Use of Brazilian eucalyptus to produce LVL panels," *For. Prod. J.* 54(10), 61-64.

Çolak, S., Aydın, İ., Demirkır, C., and Çolakoğlu, G. (2004). "Some technological properties of laminated veneer lumber manufactured from pine veneers with melamine added - UF resins," *Turk J. Agric. For.* 28(2), 109-113.
Çolak, S., Çolakoğlu, G., and Aydın, I. (2007). "Effects of logs steaming, veneer drying and aging on the mechanical properties of laminated veneer lumber (LVL)," *Build and Environ* 42, 93-98.
Gillespie, R. H., and River, B. H. (1976). "Durability of adhesives in plywood," *For. Prod. J.* 26(10), 21-25.
Kılıç, Y., Çolak, M., Baysal, E., and Burdurlu, E. (2006). "An investigation of some physical and mechanical properties of laminated veneer lumber manufactured from black alder (*Alnus glutinosa*) glued with polyvinyl acetate and polyurethane adhesives," *For. Prod. J.* 56(9), 56-59.
Kılıç, M. (2011). "The effects of the force loading direction on bending strength and modulus of elasticity in Laminated Veneer Lumber (LVL)," *BioResources* (http://www.bioresources.com), 6(3), 2805-2817.
Kojima, M., Yamamoto, H., Yoshid, M., Ojio, Y., and Okumura, K. (2009). "Maturation property of fast-growing hardwood plantation species: A view of fiber length," *For. Ecology and Management* 257, 15-22.
Kurt, R. (2010). "Suitability of three hybrid poplar clones for laminated veneer lumber manufacturing using melamine urea formaldehyde adhesive," *BioResources* (http://www.bioresources.com), 5(3), 1868-1878.
Lee, J. N., Tang, R. C., and Kaiserlik, J. H. (1999). "Edge static bending properties of yellow-poplar laminated veneer lumber: effect of veneer-joint designs," *For. Prod. J.* 49(7/8), 64-70.
Ozarska, B. (1999). "A review of the utilization of hardwoods for LVL," *Wood Sci Technol* 33, 341-351.
Saviana, J., Sosa, Z. M. A., and Piter, J. C. (2009). "Bending strength and stiffness of structural laminated veneer lumber manufactured from fast-growing Argentinean *Eucalyptus grandis*," *Maderas Ciencia Y Tecnología* 11(3), 183-190.
Shukla, S. R., and Kamdem, P. D. (2008). "Properties of laminated veneer lumber (LVL) made with low density hardwood species: Effect of the pressure duration," *Holz Roh Werkst.* 66, 119-127.
Shukla, S. R., and Kamdem, P. D. (2009). "Properties of laboratory made yellow poplar (*Liriodendron tulipifera*) laminated veneer lumber: Effect of the adhesives," *Eur. J. Wood Prod.* 67, 397-405.
Wang, B. J., and Dai, C. (2005). "Hot-pressing stress graded aspen veneer for laminated veneer lumber (LVL)," *Holzforschung* 59, 10-17.

Article submitted: April 15, 2012; Peer review completed: May 28, 2012; Revised version received and accepted: May 29, 2012; Published: May 31, 2012.