Effects of Steaming, Drying Temperature, and Adhesive Type on Static Bending Properties of LVL made of *Picea orientalis* and *Abies nordmanniana* veneers

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The modulus of elasticity (MOE) and modulus of rupture (MOR) were evaluated for laminated veneer lumber (LVL) in static bending. The studied species were spruce (*Picea orientalis*) and fir (*Abies nordmanniana*) originated from the Eastern Black sea region and prepared with phenol-formaldehyde and melamine-urea-formaldehyde. The effect of wood species, steaming, drying temperature, and type of adhesive on static bending MOE and MOR were determined. According to the experimental results, the bending strength of spruce wood (Maçka) treated with phenol formadehyde adhesives is the highest for the specimens steamed for 6 h at a drying temperature of 110 ºC. Furthermore, the modulus of elasticity for spruce wood (Maçka) treated with phenol formadehyde adhesive is the highest for the specimens steamed for 12 h and subjected to a drying temperature of 150 ºC.

Keywords: Adhesives; Bending strength; Modulus of elasticity; Laminated veneer lumber

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INTRODUCTION

In recent years, declining forest resources, both locally in Turkey as well as globally, have led to the conclusion that wood obtained from the forest should be utilized in such a way as to achieve high yield and with improved engineering properties. Therefore, wood-based building materials (EWP-engineered wood products) have been created, and many new products have been developed using the material (Dallı 2005). Recently, laminated veneer lumber (LVL) has been developed. LVL is a versatile engineered product that combines the best of modern processing technology for use of peeled veneer wood. LVL was first used to make airplane propellers and other high-strength aircraft parts during World War II, and after the mid-1970s it has attracted considerable interest for building applications (CWC 1997; URL-1, 2014). LVL has been used structurally for several years in the Northern America and in many European countries. Specifically in the United States, layered wooden material produced by the peeling method of softwood species through heating and steaming, are known to be used in construction and other fields (Karacabeyli and Rainer 2000; URL-1, 2014).

LVL shrinks and swells less than solid wood (Keskin 2001). The laminated wood material, being superior in terms of aesthetic, economic, and technological properties in comparison to solid wood, is preferred for frame elements of furniture that require strength, *e.g*. cabinets, tables, chairs, shelves, and upholstery furniture (Eckelman 1993; Okçu 2006). The strength of laminated products depends on the quality and the technical characteristics of the glue, the structure of the wood, the surface roughness, the applied pressure, and pressing time. In the case of simultaneously pressing different wood species, the parameters of the applied pressure are determined by the softer wood species (Dilik 1997). Shukla and Kamdem (2009) investigated that effect of the adhesives on the MOR and MOE properties of laminated veneer lumber (LVL) produced from *Liriodendron tulipifera*. MUF, MF, UF, and PVAc were used for this aim, and the results showed that the MOR and MOE values of LVL bonded with PVAc were slightly lower than LVL bonded with thermosetting adhesives. Aydın and Çolak (2003) examined the change in the physical and mechanical properties after steaming spruce (*Picea orientalis* L.) wood, and reported a decrease in specific gravity of air dried, the equilibrium moisture content, rates of contraction and expansion in the radial direction, and the mechanical strength properties (bending and shock strength) of the steamed spruce and found that the mechanical properties, especially the bending and impact strengths of steamed specimens decreased.

The aim of this study was to determine the effects of steaming time, growth conditions, drying temperature, and type of adhesive on MOR and MOE in static bending of LVL manufactured from spruce and fir trees grown in the Eastern Black Sea region.

EXPERIMENTAL

Materials

Wood material

Oriental spruce (*Picea orientalis*) and Eastern black sea fir (*Abies nordmanniana*) woods used were obtained from the Eastern Black sea region (specifically, the Trabzon/Maçka, Gümüşhane/Torul, and Rize/Çayeli provinces. Spruce and fir wood from the location Çayeli (1200 m altitude), spruce wood from Maçka (800 m altitude), and fir wood from Torul (1400 m altitude) were collected. Wood specimens were randomly selected from among regular-fiber, knotless, crack-free, colour-free, ordinary density wood samples having annual rings perpendicular to the surfaces according to TS 2470 (1976) standards. The lengths, diameters (DBH-diameter at breast height), and ages of the Oriental spruce trees varied within the ranges 8 to 10 m, 30 to 35 cm, and 10 to 12 years, while the lengths, diameters (DBH-diameter at breast height), and ages of the Eastern black sea fir trees were in the ranges of 10 to 12 m, 45 to 55 cm, and 25 to 30 years, respectively. Logs were debarked and bucked in 60 cm long sections for veneer manufacture.

Individual logs, excluding the bottom of a log (1 meter above the soil surface) and end zone of a log, were marked as either not steamed, steamed for 6 h, or steamed for 12 h. Rotary-cut veneer with a thickness of 1.5 mm was produced from logs that were steamed at the Karadeniz Technical University Department of Forestry Industry Engineering pilot plant. Each section of the logs was steamed at a temperature of 100 ºC in a vat for 6 and 12 h before veneer production. The steam treatment was conducted under pressure (2 MPa) (TS EN 326-1 1999).

Adhesives

In this study, two adhesives were used. These adhesives were obtained Polisan Dye Industry and Trade Co-Ltd. The phenol formaldehyde (FF) adhesive contained 47 wt% solids, and the melamine-urea formaldehyde (MUF) adhesive contained 55 wt% solids consisted of 100 parts by weight of binder, 30 parts flour, and 10 parts hardener. Ammonium chloride (NH_4Cl, 15% concentration) was used as hardener for the MUF adhesive.

Methods

Preparation of laminated veneer lumber (LVL)

Nine-layer LVLs were manufactured from rotary cut veneers with dimensions of 550 x 550 x 1.5 mm (width x long x thickness) by using MUF and PF adhesives. The horizontal opening was 85% of the veneer thickness, and the vertical opening was 0.5 mm in the peeling process. The veneers were dried at 110 °C and 150 °C for 5 min until a moisture content was 6 to 8% in a commercial veneer dryer. The veneer gluing process was performed on a gluing machine with four cylinders. The amount of adhesive was m^2 to 160 g. After the gluing process, nine veneer sheets were laid with the fiber directions parallel each other and pressed in a single-ply hydraulic hot press with a pressing area of 70 x 89 cm. Hot press time and pressure were 20 min and 8 kg/cm^2, respectively, press temperature was 110 °C for MUF and 140 °C for PF. Test panels were conditioned to achieve equilibrium moisture content (EMC) at 20 °C temperature and 65% relative humidity for a week after pressing. Five experimental panels were produced per group. The thickness of the LVL was about 14 mm and width and length of LVL were 20 mm and 300 mm, respectively.

Bending strength and modulus of elasticity

Experiments were tested on a Universal Testing Machine having a capacity of 4 tons. Bending strength tests were carried out according to TS EN 310 (1999) and TS 2474 (1976). Test specimens were cut in dimensions of 20 x 14 x 300 mm (width x height x long). The distance between points of support was 240 mm. In the experiments, the load was applied in the middle of the specimens and loading rate of the test machine was approximately 2 mm/min; 20 test specimens in each group were used.

The bending strength was calculated according to Eq. 1,

$$\text{MOR} = (3 \times F_{\max} \times L_s) / (2 \times b \times h^2) \ (\text{N/mm}^2) \quad (1)$$

where MOR is bending strength (N/mm^2), $F_{\max}$ is maximum force during the test (N), b is the width of the specimens (mm), h is thickness of the specimens (mm), and L_s is the openness between two support on the mechanism (mm).

The modulus of elasticity was determined according to Eq. 2,

$$MOE = \frac{\Delta F x Ls^3}{4 x \Delta f x b x h^3} (N / mm^2) \quad (2)$$

where MOE is modulus of elasticity (N/mm^2), ΔF is difference between first load (F_1) with second load (F_2) (N), L_s is the openness between two support on the mechanism (mm), Δf is strain, the amount the material yields (elongation per unit length) (mm), b is the width of the specimens (mm), and d is the thickness of the specimens (mm).

Statistical evaluation

A statistical software package called SPSS 12.0 was used in the statistical evaluation of the data. In the analysis, the values of factors were determined based on a multiple variance analysis. Factor effects were considered significant with α=0.05 risk level. ANOVA was used to analyze the effects of species, growth conditions, adhesive type, steaming and drying temperature on the MOE and MOR of spruce and fir LVL.

RESULTS AND DISCUSSION

Bending Strength (MOR) of LVL

MOR values of LVL according to the type of wood, drying temperatures, steaming process, and type of adhesive are given in Table 1. The interaction between these obtained values was examined by ANOVA, and the results obtained are given in Table 2.

Table 1. Mean Values of MOR of LVL (N/mm²)

	Drying Temperature	110 ºC					
	Steaming Conditions	No steam (Control)		6 h steamed		12 h steamed	
Sample Groups	Type of Adhesive	FF	MUF	FF	MUF	FF	MUF
ML	$\bar{X}$ S	95.39 11.52	75.98 6.70	72.12 7.33	77.57 3.51	51.69 12.44	62.41 2.85
ÇL	$\bar{X}$ S	51.27 5.23	53.98 6.63	54.74 3.77	54.64 4.43	57.91 5.03	60.64 3.78
ÇG	$\bar{X}$ S	63.30 7.43	51.41 7.06	63.57 5.50	52.08 4.88	57.15 7.03	80.87 6.45
TG	$\bar{X}$ S	71.38 8.27	64.00 5.19	70.95 4.14	63.25 6.27	72.91 7.24	60.66 5.67
	Drying Temperature	150 ºC					
	Steaming Conditions	No steam (Control)		6 h steamed		12 h steamed	
Sample Groups	Type of adhesive	FF	MUF	FF	MUF	FF	MUF
ML	$\bar{X}$ S	86.90 5.56)	51.48 6.81	85.13 7.09	78.86 7.28	73.21 5.30	70.80 5.48
ÇL	$\bar{X}$ S	57.26 3.24)	54.72 4.55	50.90 4.57	51.73 4.13	56.90 4.01	57.08 5.77
ÇG	$\bar{X}$ S	60.18 5.57)	62.06 11.53	56.77 4.69	53.67 5.16	59.32 5.69	54.29 5.93
TG	$\bar{X}$ S	64.52 7.73)	64.59 3.39	70.58 6.24	63.14 5.39	63.28 4.22	59.28 4.22

$\bar{X}$, Mean; S, Standard Deviation; ML, Maçka/Spruce Wood; ÇL, Çayeli/Spruce wood; ÇG, Çayeli/Fir wood; TG, Torul/Fir wood; FF, Phenol formaldehyde; MÜF, Melamine-Urea formaldehyde

According to the results of the analysis of variance, the effects of the type of wood, steaming, and type of adhesive on the values of MOR of specimens were found to be significant, with 5% error ($P<0.05$); however, the effect of drying temperature was not significant ($P>0.05$). MOR values of LVL made from spruce wood (Çayeli) at 110 °C showed partial increases (54.74 6h FF, 57.59 12h FF). On the contrary, MOR values of LVL made from spruce wood (Maçka) were decreased (77.57 6h MUF, 62.41 12h MUF). At the same drying temperature, the type of adhesive, temperature, and steaming time did not cause significant changes on MOR values of LVL made from fir wood (Çayeli and Torul). MOR values of LVL made of spruce (Maçka) with MUF steamed for 6 h and 12 h at 150 °C were increased (51.48, 78.86), whereas MOR values of LVL made of spruce (Maçka) with FF at the same steaming time and drying temperature according to no-steamed wood were decreased (86.90 no-steam, 73.21 12h).

Table 2. Results of MOR Multiple Variance Analysis

Variance source	Sum of squares	Degrees of Freedom	Mean squares	F test	Level of Significance (P<0.05)
A:Type of Wood	653.325	1	653.325	20.60	0.0000*
B:Steaming	626.512	2	313.256	9.88	0.0000*
C:Drying temperature	2.70008	1	2.70008	0.09	0.7930$^{N.S}$
D:Type of adhesive	607.473	1	607.473	19.16	0.0000*
Interaction AB	979.968	2	489.984	15.45	0.0000*
Interaction AC	67.0371	1	67.0371	2.11	0.0522$^{N.S}$
Interaction AD	1091.48	1	1091.48	34.42	0.0000*
Interaction BC	939.575	2	469.787	14.82	0.0000*
Interaction BD	103.598	2	51.7992	1.63	0.1873$^{N.S}$
Interaction CD	141.175	1	141.175	4.45	0.0134*
Interaction ABC	33.1653	2	16.5827	0.52	0.638$^{N.S}$
Interaction ABD	61.6657	2	30.8329	0.97	0.4070$^{N.S}$
Interaction ACD	528.566	1	528.566	16.67	0.0000*
Interaction BCD	375.55	2	187.775	5.92	0.0035*
Interaction ABCD	488.797	2	244.399	7.71	0.0000*
Error	14459.7	456	31.7099		
Total	21160.3	479			

*, significant at 95% confidence level (P<0.05); N.S, not significant (P>0.05)

Although MOR values of LVL made of spruce (Çayeli) steamed for 6 h were increased a bit, the values did not exhibit significant changes when steaming 12 h, at 150 °C. At the same drying temperature, MOR values of LVL made of Fir (Çayeli) showed minor decreases (60.18, 56.77). However, MOR values of LVL made of Fir (Torul) were close to those of non-steamed wood (64.59 non-steam MÜF, 63.14 6h MÜF). The cause of the partial reduction of the bending strength values can be altitude, soil characteristics, anatomical structures, permeability, specific weight, amount of the resin, and structure of parenchyma cells.

Modulus of Elasticity of LVL

MOE values of LVL according to the type of wood, drying temperatures, steaming process, and type of adhesive, as well as the results of the analysis of variance, are given in Tables 3 and 4. According to the results of the analysis of variance, the effects of the type of wood, drying temperature, steaming, and type of adhesive on MOE values of LVL and interactions between in groups, except of interaction between the drying temperature with type of adhesive, were found to be significant, with 5% error (P<0.05). LVL made of spruce had the highest MOE (9625.65 N/mm^2), while LVL made of fir had the lowest MOE (3684.46 N/mm^2). In general, the MOE values of LVL with FF adhesive were higher than those for LVL with MUF adhesive (5666.63 6h 110 ºC FF ÇG, 4528.92 6h 110 ºC MUF ÇG), but MOE values of LVL made of spruce with MUF steamed for 6 h and 12 h at 110 ºC spruce (6381.11 FF, 6416.90 MUF) and LVL made of fir with MUF steamed for 12 h at 150 ºC were higher than for FF because of anatomical structure and specific weight of spruce, growth conditions, structure of bond of adhesives, and altitude.

Table 3. Mean Values of MOE for LVL (N/mm²)

	Drying Temperature	110 ºC					
	Steaming Conditions	No steam (Control)		6 h steamed		12 h steamed	
Sample groups	Type of Adhesive	FF	MUF	FF	MUF	FF	MUF
ML	$\bar{X}$	8305.41	7920.53	6381.11	6416.90	4206.10	5852.87
	S	748.12	1239.39	590.14	405.29	994.73	351.18
ÇL	$\bar{X}$	4540.06	4459.27	4157.43	4554.24	4487.43	4704.32
	S	444.08	432.73	366.32	605.15	495.82	795.72
ÇG	$\bar{X}$	5607.58	3684.46	5663.42	4528.92	5833.29	7569.14
	S	543.79	404.63	751.83	257.65	619.82	296.12
TG	$\bar{X}$	7492.32	6243.26	7213.88	5953.78	7144.24	5514.02
	S	946.25	805.97	481.32	516.23	882.18	364.86
	Drying Temperature	150 ºC					
	Steaming Conditions	No steam (Control)		6 h steamed		12 h steamed	
Sample groups	Type of Adhesive	FF	MUF	FF	MUF	FF	MUF
ML	$\bar{X}$	8404.742	4646.75	8244.73	5765.86	9625.65	6080.91
	S	646.08	369.51	379.97	674.02	401.32	363.98
ÇL	$\bar{X}$	5449.38	4470.28	4559.82	4555.43	4314.10	4137.47
	S	405.50	399.97	446.82	690.76	238.60	414.48
ÇG	$\bar{X}$	4527.67	4982.54	4944.10	4528.12	5062.83	4461.57
	S	581.64	1290.99	620.58	257.65	404.69	375.74
TG	$\bar{X}$	6370.43	6188.83	7189.92	5534.13	4716.34	5018.64
	S	913.03	591.71	515.27	292.14	462.72	505.42

$\bar{X}$, Mean; S, Standard Deviation; ML, Maçka/Spruce Wood; ÇL, Çayeli/Spruce wood; ÇG, Çayeli/Fir wood; TG, Torul/Fir wood; FF, Phenol formaldehyde; MÜF, Melamine-Urea formaldehyde

Higher drying temperature appeared to negatively affect the MOE of LVL made of fir (4528.92 6h 110 ºC MUF ÇG, 4528.12 6h 150 ºC MUF ÇG). There was a direct correlation between the MOE values of LVL made of spruce with drying temperature (6381.11 6h 110 ºC FF ML, 8244.73 6h 150 ºC FF ML), generally. Although there was a direct correlation between the MOE values of LVL with steaming time (4206.10 6h 110 ºC FF ÇG, 5833.29 12h 110 ºC FF ÇG), steaming time appeared to negatively affect the MOE of LVL made of fir (Çayeli) at 110 ºC and spruce (Maçka) and fir (Çayeli) with FF at 150 ºC (4944.10 6h 150 ºC FF ÇG, 5062.83 12h 150 ºC FF ÇG). In regard to growth conditions, the MOE values of LVL from spruce (Torul) and fir (Maçka) woods was higher than MOE values of LVL manufactured from spruce and fir (Çayeli) wood (9625.65 12h 150 ºC FF ML, 4314.10 12h 150 ºC FF ÇL).

Aydın *et al*. (2004) conducted a study of physical and mechanical strength properties of LVL panels made from eucalyptus (*Eucalyptus camaldulensis* Dehn.) using UF, and PVA adhesives and beech (*Fagus orientalis* Lipsky.) veneers using UF and found that not only the static bending strength value for beech LVL panels (118.3 N/mm^2) was evidently higher than that for eucalyptus LVL panels (94.6 N/mm^2), but also the static bending strength of LVLs produced with UF adhesive was higher than that of LVLs produced with PVA adhesive.

Table 4. Results of MOE Multiple Variance Analysis

Variance source	Sum of squares	Degrees of Freedom	Mean squares	F test	Level of Significance (P<0.05)
A: Type of Wood	1.0879E7	1	1.0879E7	34.99	0.0000*
B: Steaming	2.40498E6	2	2.40498E6	3.87	0.0217*
C: Drying temperature	1.35609E6	1	1.35609E6	4.36	0.0124*
D: Type of adhesive	1.40263E7	1	1.40263E7	45.11	0.0000*
Interaction AB	1.12617E7	2	5.63083E6	18.11	0.0000*
Interaction AC	5.69368E6	1	5.69368E6	18.31	0.0000*
Interaction AD	7.59518E6	1	7.59518E6	24.42	0.0000*
Interaction BC	9.1323E6	2	4.56615E6	14.68	0.0000*
Interaction BD	1.12255E7	2	5.61274E6	18.05	0.0000*
Interaction CD	219,227	1	219,227	0.00	0.9870$^{N.S}$
Interaction ABC	5.96355E6	2	2.98178E6	9.59	0.0000*
Interaction ABD	1.34478E7	2	6.72391E6	21.62	0.0000*
Interaction ACD	8.39004E6	1	8.39004E6	26.98	0.0000*
Interaction BCD	8.87908E6	2	4.43954E6	14.28	0.0000*
Interaction ABCD	1.85145E7	2	9.25723E6	29.77	0.0000*
Error	1.41797E8	456	310959.0		
Total	2.70567E8	479			

* significant at 95% confidence level (P<0.05); N.S, not significant (P>0.05)

Çolak *et al.* (2007) examined the effects of steaming and drying condition on the mechanical properties and durability of LVL and solid sawn lumber in a comparative way. Steamed beech and steamed and non-steamed spruce logs were used and two different veneer drying temperatures (20 and 110 °C) were selected. Consequently, it was found that the effect of steaming on the bending strength of LVL made from spruce wood was negative and veneer-drying temperatures selected had no significant effect on the static bending strength of the panels. Bal and Bektaş (2012) evaluated the effects of species of tree, the direction of the load, and type of adhesive on the MOR, MOE, and specific modulus of rupture (SMOR), and specific modulus of elasticity (SMOE) of LVL, and the results showed that the differences among species of tree, and the direction of the load on the MOR, MOE, SMOR, and SOME were statistically significant. In addition, the effect of type adhesive on the MOR was significant.

CONCLUSIONS

The effects of tree species, steaming time, drying temperature, and type of adhesive were determined relative to the static bending of LVLs bonded with formaldehyde-based adhesive. The results showed that:

1. The MOR (64.30, 62.63 N/mm^2) and MOE (5676.67, 5665.55 N/mm^2) values for LVL made of spruce were higher than the values for LVL made of fir.
2. The highest MOR (73.46 N/mm^2) and MOE (6820.9 N/mm^2) values were calculated for LVL made of growing wood from Maçka district. The lowest MOR (57.22 N/mm^2) and MOE (4824.28 N/mm^2) values were determined for LVL made of growing wood from Çayeli district.
3. The MOR (65.3, 61.63 N/mm^2) and MOE (6018.39, 5323.84 N/mm^2) values for LVL bonded with FF adhesive were higher than the values for LVL bonded with MUF.
4. As drying temperature increased, MOR (64.16, 62.77 N/mm^2) and MOE (5768.0825, 5574.1768) values for LVL were decreased.
5. The highest MOR (64.27 N/mm^2) and MOE (5830.79 N/mm^2) values were calculated for LVL made of non-steamed wood. The lowest MOR (62.4 N/mm^2) and MOE (5545.55 N/mm^2) values were calculated for LVL made of steamed wood for 12 h. That is, there was negative relationship between MOR and MOE values with steaming time.

As a result of experiments, it was determined that MOR and MOE values of laminated wood are superior than solid wood. Therefore, one can propose the use of laminated wood of the same species instead of solid wood at places where heavy loads may be applied, so that a sufficiently high strength of wood is desired. Also, due to the use of small-sized wood pieced in lamination, the product cost and the proportion of waste material are both reduced significantly. The laminated spruce and fir wood materials may be used for structural and non-structural applications, stairs, ceiling, walls, flooring, doors, windows, border production, in aesthetically pleasing interiors, furniture production, sports equipment, music instruments production, and in the packing industry.

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Article submitted: June 14, 2014; Peer review completed: August 28, 2014; Revised version received: October 22, 2014; Accepted: October 28, 2014; Published: November 7, 2014.