

Determination of Some Physical and Mechanical Properties of Laminated Veneer Lumber Impregnated with Boron Compounds

Ayhan Özçifçi,¹ Yalçın örs,² Burhanettin Uysal³

¹Karabük Technical Education Faculty, Zonguldak Karaelmas University, 78050 Karabük, Turkey

²Technical Education Faculty, Gazi University, 06580 Ankara, Turkey

³Safranbolu College, Zonguldak Karaelmas University, 78600 Karabük, Turkey

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ABSTRACT: The aim of this study was to determine the effects of Tanalith-C 3310 (T-C 3310), borax (Bo), boric acid (Ba), borax + boric acid (Bo + Ba), and diammonium phosphate (D) impregnations for some physical and mechanical properties of laminated veneer lumber (LVL). The veneers used for the LVL samples (based on BS EN 204) were cut from Scots pine (*Pinus sylvestris* L.), oriental beech (*Fagus orientalis* L.), and poplar (*Populus nigra*). They were impregnated with full-cell method according to ASTM-D 1413 standards and bonded with phenol formaldehyde (PF) and melamine formaldehyde (MF) adhesives. The following parameters have been tested: density, compression strength, bending strength, modulus of elasticity (MOE) in bending, and shear strength tests.

Test results obtained from this study showed that impregnation with Boric acid and Tanalith-C 3310 (based acidic characteristic) affected the strength of LVL negatively, when the wood material is impregnated with acidic impregnations and bonded with PF, which is an alkali, the glue-line becomes more elastic, the bonding strength of adhesive weakens. Boric acid and Tanalith-C 3310 impregnations could not be recommended for LVL elements exposed to bending or shear strength. © 2007 Wiley Periodicals, Inc. *J Appl Polym Sci* 105: 2218–2224, 2007

Key words: density; compression; bending strength; MOE; shear strength; boron compounds

INTRODUCTION

With increasing use of lumber for exterior applications, the concerns about insect attack, fungal degradation, or weathering lead to treatment of lumber with various wood preservatives. Thus, wood treated with waterborne preservatives are being used for various exterior applications such as structural and nonstructural assemblies. An enhanced adhesion of treated woods to bond-treated lumber and their greater durability obviously increase the use of treated woods for exterior applications.¹

Many factors contribute to the development of insufficient adhesive strength of treated woods. The presence of contaminants such as waxy, oily, and inorganic materials hinders the development of cohesive adhesion bonds between wood substrate and adhesive.²

Oriental beech, Uludağ fir, and Scots pine were treated with Tanalith-CBC (T-CBC) and Imer-sol-WR 2000 (I-WR 2000), both of which are impregnations, and were then bonded with four different adhesives (PVAc, K₃₀₃, K_{305.0}, SL₃₀₈ based on PVAc).

The shear strength tests showed that, the highest value (11.84 N mm⁻²) was obtained for oriental beech treated by Imer-sol-WR 2000 and bonded with K₃₀₃ using a dipping method. The lowest shear strength (3.1 N mm⁻²) was found for Scots pine treated with T-CBC with K_{305.0} using a vacuum method.^{3,4}

Aspen veneers were treated with five waterborne emulsions and bonded with PF adhesive. The effectiveness of adhesion was determined by measuring the shear strength and the portion of wood failure when the wood was saturated with water before testing. The type of the preservative, the retention amount, and the length of assembly time, all affected the durability of the bonds significantly.^{5–7} In literature, pressure treatment with wood preservatives has been reported to interfere with the bond integrity of solid wood glued specimens. The preservative type, the preservative retention, and the interaction with the surface have been reported as highly significant factors affecting the shear strength of glue bonds in solid wood samples.^{8,9}

Investigations showed that durability, mechanical properties, and engineering performance of LVL were affected by many factors, such as wood species, thickness and quality of the used veneers, processing variables, or the dimensions of LVL. It was shown that treatment with boric acid affected the compres-

Correspondence to: A. Özçifçi (aozciftci@hotmail.com).

TABLE I
Peculiarities of Impregnation Chemicals

Impregnation chemicals	Viscosity (mPa s)	Concentration of solution (%)	Temperature (°C)	pH		Density (g/cm ⁻³)	
				B.I.	A.I.	B.I.	A.I.
Borax (Bo)	8.000 ± 2.000	5	20	9.05	9.10	1.035	1.038
Boric acid (Ba)	8.000 ± 2.000	5	20	4.56	4.60	1.030	1.034
Bo + Ba	8.000 ± 2.000	5 (50 : 50)	20	7.91	7.96	1.030	1.035
Diammonium phosphate (D)	8.000 ± 2.000	5	20	6.64	–	1.07	–
D-(Bo + Ba)	9.000 ± 2.000	5 [50 : (25 + 25)]	20	5.08	5.13	1.11	1.13
T-C 3310	11.000 ± 2.000	^a	20	2.48	2.57	1.70	1.76

B.I., before impregnation; A.I., after impregnation.

^a Viscosity of package.

sion strength in tangential direction of the veneers negatively.¹⁰ Higher modulus of elasticity values were observed in the samples impregnated with Imersol Aqua, produced by Hemel, Istanbul-Turkey, by short term-dipping method. Accordingly, it is pointed out that, except for Scots pine, the modulus of elasticity in bending increased with the higher retention amount of the impregnation material.¹¹

The aim of this study here was to determine some physical and mechanical effects of the impregnation with boron compounds and T-C 3310 on the modulus of elasticity, compression strength, bending strength, shear strength, and density of LVL, obtained from Scots pine and oriental beech veneers and bonded with PF and MF adhesives.

MATERIALS AND METHOD

Wood materials

Scots pine (*Pinus sylvestris* L.), Oriental beech (*Fagus orientalis lipsky*), and poplar (*Populus nigra*) were commercially purchased in Turkey. The density of the Scots pine was 0.49 g cm⁻³, density of Oriental beech was 0.54 g cm⁻³, and density of poplar was 0.41 g cm⁻³. According to EN 204, nondeficient, proper, knotless, and normally grown wood, reaction wood, decay or insect or fungal damages was selected.

Impregnation materials

The following impregnating solutions supplied by Hemel (Istanbul-Turkey) were used:

- Tanalith-C 3310 (T-C 3310) containing 47% Cr₂O₃, 19% CuO, 34% As₂O₅;
- Borax (Bo) (Na₂B₄O₇·5H₂O) containing 21.28% Na₂O, 47.80% B₂O₃, 30.92% H₂O;
- Boric acid (Ba) (H₃BO₃) containing 56.30% B₂O₃, 43.70% H₂O;
- Bo + Ba mixture (each 50% by weight).

Di-ammonium phosphate (D) [(NH₄)₂HPO₄] was mixed with (Bo + Ba) to obtain [D + (Bo + Ba)].

The composition of the [D + (Bo + Ba)] with the composition 50% D, 25% Bo, and 25% Ba by weight.

Boron compounds were chosen for the experiments because they are easily available and cheaper than the other impregnating materials that are non-flammable.

T-C 3310 impregnating substance is widely used as a fire retardant and as preservative against fungal attack. It was also preferred compared to other inorganic waterborn preservatives because of the low cost and good availability.

Details of the used impregnation solution used in the experiments are given in Table I. There is no change in both, pH and the density of the solution before and after impregnation solutions have been used.

Adhesives

Phenol-formaldehyde (PF), melamine-formaldehyde (MF), and their mixtures are commonly used in woodworking industries and were chosen as adhesives in this study. Nowadays, in literature, MF resins have been preferred as mixing type with urea-formaldehyde resins or phenol formaldehyde resins.⁷⁻¹⁰ However, an investigation carried out by Özçifçi indicated that MF adhesive could be used for LVL industry.⁷ The reason for not using pure MF^{12,13} adhesives in industry is that it is more expensive than the other resins mentioned here. The characteristics of the used MF and PF adhesives are summarized in Table II.¹⁴

Impregnation process

All veneer specimens for impregnation or testing were first oven-dried at (103 ± 2)°C for 12 h and placed in a vacuum chamber (<3 mmHg) at 30°C for 1 h. The impregnating solutions containing Bo, Ba, Bo + Ba, D-(Bo + Ba), T-C 3310 were filled into the vacuum chamber until the veneer samples were covered. After 1 h of impregnation at 30°C, the vacuum released and the impregnation process was continued for another 1 h.¹⁵

TABLE II
Characteristics of Adhesives

	Density (g cm ⁻³)	pH	Viscosity (mPa s)	Time to solidify at 110°C (min)	Gel time at 20°C (min)	Amount applied (g m ⁻²)
Phenol formaldehyde	1.15	7.5	13.000 ± 2.000	2–4	15–20	180
Melamine formaldehyde	1.22	9.3	12.000 ± 3.000	2–3	15–20	180

Then, the veneer samples were removed and wiped to remove excess impregnating solution from the veneer surfaces. Finally, the veneer specimens were dried in oven at (103 ± 2)°C for 12 h before gluing and pressing.

Preparation of test samples

The wood samples were kept at a temperature of (20 ± 2)°C and at (65 ± 3)% relative humidity in a conditioned room until their weights became constant. Before the panels' production, the beech, pine, and poplar woods were sliding cut as 2.5 mm-thickness and veneers were obtained for LVL. Veneer sheets were dried at 110°C for 5 min in a veneer drier having relative humidity from 40–50% to 5–7%. Then, the impregnating process was carried out according to ASTM-D 1413-76 standards. Finally, the veneers were bonded using phenol-formaldehyde and melamine-formaldehyde adhesives. Eight-layer LVL panels with 20 mm thickness were manufactured: two poplar veneers were used for core ply; three beech or Scots veneers were used as outer plies. The PF and MF adhesives were applied to one of the surfaces of each veneer with ~ 180 g mm⁻², using a roller gluing machine. Hot pressing was performed in a lab press at a specific pressure of 1.2 N mm⁻² and a press time of 7 min. The press temperature was adjusted to 120°C according to recommendations

given by the manufacturer. The size of the produced LVL panels was 75 × 75 cm² and five replicate panels were manufactured for each test group.

All test samples prepared for bending strength, modulus of elasticity, compression, shear strength, and density were longitudinal to the grain direction. The samples were tested after being conditioned at (20 ± 2)°C and at (65 ± 3)% relative humidity.

Mechanical tests

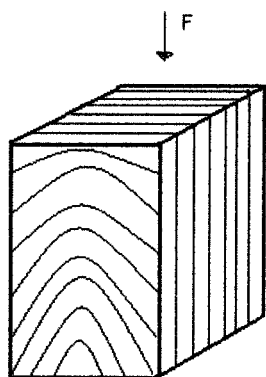
Compression strength was measured according to TS 2595. The dimensions of test samples were 20 × 20 × 30 mm³.^{16,17} The test was performed on a 40 kN universal test machine and crosshead motion or rate of loading was 0.5 mm/min. Ten samples of each, untreated LVL and LVL made from impregnated veneers, were tested (Fig. 1). The compression strength (σ_C) longitudinal to grain was calculated by the following equation:

$$\sigma_C = F/A \text{ (N mm}^{-2}\text{)} \quad (1)$$

where F is the maximum force (N) and A is the cross-sectional area (mm²).

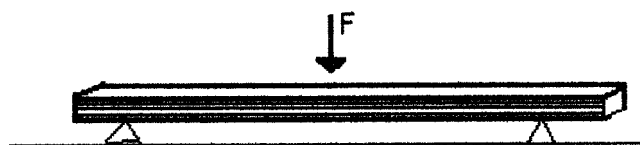
Bending strength was measured by a universal testing machine according to the procedure in TS 2474.¹⁸ For this test, untreated LVL (20 × 20 × 360 mm³) and LVL made from impregnated veneers were tested (Fig. 2). Ten replications were performed for the control and for the impregnated samples. The bending strength (σ_B) was calculated with the following equation:

$$\sigma_B = 1.5FL/ab^2 \text{ (N mm}^{-2}\text{)} \quad (2)$$



2x2x3 cm dimensions of LVL

Figure 1 Compression strength test in longitudinal direction.



2x2x36 cm dimensions of LVL

Figure 2 Test sample of static bending and modulus of elasticity.

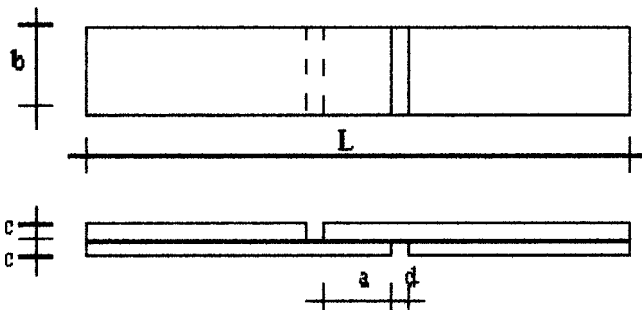


Figure 3 Shear strength test sample (a , 10 mm; b , 20 mm; c , 5 mm; d , 3 mm; L , 150 mm).

where F is the maximum force (N), L is the span (mm), a is the cross-sectional width of the test sample (mm), and b is the cross-sectional thickness of the test sample (mm).

The test for modulus of elasticity in bending mode was carried out with the Universal Testing Equipment according to TS EN 310.¹⁹ For this test, untreated LVL ($2 \times 2 \times 36 \text{ cm}^3$) and impregnated LVL samples were used (Fig. 2). The deformations of the test samples were measured in the middle of the specimens within a zone of five times the width of the sample using a comparator.¹¹ The deformations were assessed with a sensitivity of 0.01 mm. In the elastic deformation zone, the modulus of elasticity (MOE) was calculated with the following formula:

$$MOE = \frac{\Delta FL^3}{4bh^3\Delta f} \quad (\text{N mm}^{-2}) \quad (3)$$

where ΔF is the difference between the arithmetic average of the upper and the lower force applied in the elastic deformation zone (N), Δf is the net elastic deflection calculated as difference between the measured elastic deflection in the upper and the lower loading limits (mm), L is the span (mm), b is the cross-sectional width of the test sample (mm), and h is the cross-sectional thickness of the test sample (mm).

The measurement of shear strength was carried out in a Universal testing machine, according to EN 204²⁰ and EN 205.²¹ The loading speed was 5 mm/min. The loading was carried out until a break or separation occurred on the surface of the test samples (Fig. 3). The shear strength (σ_k) was calculated using the observed load (F_{max}) and bonding surface of sample (A , mm^{-2}) according to the following formula:

$$\sigma_k = F_{\text{max}}/A = F_{\text{max}}/ab \quad (\text{N mm}^{-2}) \quad (4)$$

where a is the width of the glued face (10 mm) and b is the length of glued face (20 mm).

Data analyses

Data were further analyzed with the MSTATC statistical package (MSTATC, Michigan State University, East Lansing, MI) using a two-way analysis of variance and followed by Duncan tests at the 95% confidence level. Statistical evaluations were made on homogeneity groups (HG) where different letters reflected statistical significance.

RESULTS AND DISCUSSION

The densities of the veneers showed differences due to the impregnating process. The highest density was obtained in beech and pine LVL treated with T-C 3310, while the lowest was observed with Bo (Table III). The density of T-C 3310 is 1.70 g cm^{-3} , so it could have caused an increase in the density of LVL by impregnated veneers. The average compression strength and bending strength of impregnated LVL samples were also compared with those of untreated LVL (Table IV). The compression strength of all samples was decreased by 4–36% for beech LVL and by approximately 6–39% for pine LVL, always compared to untreated LVL. So, the properties of impregnated LVL samples were found to be worse compared to the control samples. Ba and T-C 3310, both of which are acidic, obviously have caused this weakening of the wood substance. These results are consistent with the literature. In literature, it was stated that the strength of LVL was decreased while the retention amount and the acidic value increased.^{8–10} In a similar study, treated wood often contains many defects such as twist, checks, or splits on its surfaces after its drying and curing processes. Furthermore, the formation of effective adhesive bonds in treated woods is interfered by the preservative compounds present on the surface of treated woods.²²

TABLE III
Increase in Densities of LVL Samples (g cm^{-3})

Type of adhesive	Impregnation chemicals	Beech		Pine	
		Density	%	Density	%
Phenol formaldehyde	Control	0.56	–	0.50	–
	Bo	0.59	5	0.51	1
	Ba	0.59	5	0.53	3
	Bo + Ba	0.60	6	0.52	3
	D-(Bo + Ba)	0.61	8	0.56	10
Melamine formaldehyde	T-C 3310	0.74	24	0.64	21
	Control	0.57	–	0.51	–
	Bo	0.59	3	0.53	3
	Ba	0.61	6	0.57	10
	Bo + Ba	0.61	6	0.53	3
	D-(Bo + Ba)	0.62	5	0.55	6
	T-C 3310	0.77	25	0.65	21

TABLE IV
Compression Strength in Longitudinal Direction of LVL Samples ($N\ mm^{-2}$)

Type of adhesive	Impregnation chemicals	Beech		Pine	
		X	Decrease %	X	Decrease %
Phenol formaldehyde	Control	85.31		70.41	
	Bo	75.02	13	63.67	10
	Ba	55.17	36	57.24	19
	Bo + Ba	73.75	14	63.02	11
	D-(Bo + Ba)	81.82	4	64.83	8
Melamine formaldehyde	T-C 3310	60.85	29	43.60	39
	Control	91.30		77.25	
	Bo	86.52	6	71.14	8
	Ba	70.27	24	67.76	13
	Bo + Ba	77.80	15	72.33	6
D-(Bo + Ba)	79.78	13	63.12	19	
T-C 3310	65.35	29	57.21	26	

X, average value; coefficient of variance, 3.12%.

The bending strength of the treated LVL as shown in Table V for LVL polymer composites showed a significant decrease compared to the untreated LVL. For the treated beech LVL sample this decrease was 6–60% with T-C 3310 compared to the untreated LVL. Both longitudinal compression and bending strength of LVL showed a significant decrease due to the acidic behavior of these impregnation chemicals, causing fast pre-curing reactions for adhesives in the contact with the surface of the treated wood. As a result of this, in general, both mechanical and chemical bonds between the adhesive and wood material are weak. If the adhesive does not completely penetrate crushed cells to restore their original strength, a weak joint is obtained. In the same study, it was stated that acids can catalyze the dehydration of a glucose unit and decrease the degree of polymerization (DP) of cellulose.²³

The highest MOE was obtained for the control samples, while the lowest values were observed for beech

LVL impregnated with Bo + Ba and bonded with the MF adhesive and Scots pine impregnated with Bo, bonded with PF adhesive as shown in Table VI. This maybe due to the fact that the formation of effective adhesive bonds in treated woods might have interfered by the preservative compounds. And also, Scots pine has more tracheid gaps and high retention amount, and this can cause more elastic structure for LVL. The PF adhesive reduced MOE by 22% for Scots pine LVL. It is stated that bond strengths of PF-bonded waferboard containing biological-effective levels of sodium borates or boric acid are being reported to be unacceptably low. This is most likely due to gelling of phenolic adhesive by the borate before the glue droplet can wet, transfer to, and penetrate an opposite wood surfaces.²⁴ Thus, they cause a loss in strength properties due to wood fiber network degradation. The measured shear strengths are summarized in Table VII for the various LVL samples and showed significant decreases for the treated LVL com-

TABLE V
The Average Bending Strength Values of LVL Samples ($N\ mm^{-2}$)

Type of adhesive	Impregnation chemicals	Beech		Pine	
		X	Decrease %	X	Decrease %
Phenol formaldehyde	Control	139.22		122.57	
	Bo	131.52	6	93.37	24
	Ba	97.00	31	82.44	33
	Bo+Ba	122.08	12	91.00	26
	D-(Bo + Ba)	112.46	20	100.73	18
Melamine formaldehyde	T-C 3310	56.83	60	51.53	58
	Control	145.29		113.86	
	Bo	106.21	17	100.48	12
	Ba	100.24	32	94.68	17
	Bo + Ba	129.15	12	102.01	11
D-(Bo + Ba)	125.29	14	99.81	13	
T-C 3310	77.94	47	74.20	35	

X, average value; coefficient of variance, 5.36%.

TABLE VI
MOE Values of Impregnated and Unimpregnated LVL Samples (kN mm⁻²)

Type of adhesive	Impregnation chemicals	Beech		Pine	
		X	Decrease %	X	Decrease %
Phenol formaldehyde	Control	19		30	
	Ba	19	1.1	25	15
	Ba	23	+17	22	25
	Bo+Ba	23	+19	24	20
	D-(Bo + Ba)	22	+13	23	24
Melamine formaldehyde	T-C 3310	22	+14	19	27
	Control	22		26	
	Ba	19	12	20	24
	Ba	20	10	22	17
	Bo + Ba	22	1	20	23
	D-(Bo + Ba)	22	1.1	20	23
	T-C 3310	18	20	18	30

X, average value; coefficient of variance, 9.23%.

pared to the untreated samples. The average decrease was determined by 9–45% for Scots pine LVL, and 16–32% for beech LVL. Boric acidic and T-C 3310 impregnation negatively affected the adhesion strength within LVL. LeVan and Winandy stated that acidic fire retardants can catalyze dehydration of glucose units and depolymerization of cellulose. Thus, they cause a loss in adhesion strength due to wood fiber network degradation.²⁵

Various LVL samples were made out of veneers of different wood species and partly modified by impregnation using various boron based chemicals. When the veneers were treated with boric acid and bonded with alkaline PF, the adhesive bond lines in LVL become more elastic.^{6,7,24} In a similar study, bond strengths of PF-bonded waferboard containing biological-effective levels of boric acid are reported to be unacceptable low. This is most likely due to gelling of the phenolic adhesive by the borate before

the glue droplet can wet, transfer to surface, and penetrate the second wood surface in the bond line.²⁶

Both, longitudinal compression and bending strength of LVL showed a significant reduction due to their high retention amount when the veneers were impregnated. Impregnation of veneers with Ba and T-C 3310 reduced the shear strength by 16–32% for beech LVL and by 25–39% for the Scots pine LVL. Here both T-C 3310 and boric acid might have caused degradation of the wood surface. In another study, it was stated that, this effect could negatively affect the bending strength mechanical properties of LVL; the strength of LVL decreased when the retention amount increased and with this the acidic behavior became more pronounced.^{8–10} Furthermore, acids can catalyze the dehydration of a glucose unit and decrease the degree of polymerization (DP) of cellulose.²³

TABLE VII
Average Shear Strength According to the Types of Materials (N mm⁻²)

Type of adhesive	Impregnation chemicals	Beech		Pine	
		X	Decrease %	X	Decrease %
Phenol formaldehyde	Control	10.08	–	9.04	–
	Bo	7.25	29	7.73	15
	Ba	8.47	16	6.85	25
	Bo + Ba	7.83	23	8.23	9
	D-(Bo + Ba)	7.55	25	7.75	15
Melamine formaldehyde	T-C 3310	6.92	32	5.06	45
	Control	11.83		10.00	
	Bo	8.81	25	8.46	16
	Ba	9.14	23	7.33	27
	Bo + Ba	8.49	29	8.13	19
	D-(Bo + Ba)	8.70	27	9.13	9
	T-C 3310	8.09	32	6.17	39

X, average value; coefficient of variance, 8.11%.

CONCLUSIONS

The impregnation of veneers with Ba and T-C 3310 impregnations showed the most negative effect for LVL produced out of these veneers.^{4,7} This can affect the needed properties (bending strength, shear strength) of LVL used for furniture elements and massive constructions. Therefore, impregnation with compounds causing lower retention amounts in the veneers, like various boron compounds or the D-(Bo + Ba) mixture could be recommended for the production of LVL.

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