

Effect of Boric Acid Treatment on Mechanical Properties of Laminated Beech Veneer Lumber

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Laminated veneer lumber (LVL) made from beech wood veneers treated with boric acid by using dipping method was tested for some mechanical properties following different standards. The values for treated LVL varied around the mean values of untreated LVL panels for static bending strength in the grain direction and modulus of elasticity; decreased for compression and splitting strengths, perpendicular to the grain; increased for compression strength parallel to the grain, and for Brinell hardness and pull-out strength of screw, perpendicular to surface.

Keywords treated LVL, boric acid, beech veneer, mechanical properties

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1 Introduction

In spite of many alternative materials like iron, plastic, and concrete, which can be used instead of solid wood in different areas, wood remains superior as a natural engineering material. Due to depletion of forest resources, forest products industries are faced with a crisis in obtaining suitable raw materials in sufficient amount. Therefore, layered composite materials like vertically and horizontally glued, laminated wood and Laminated Veneer Lumber (LVL) may be used as a substitute for solid wood as they retain

the structural properties of wood. Veneers from medium or small diameter logs are converted into glued parallel laminates or LVL, which is a competitive alternative for structural purposes, as its properties are superior to those of wooden planks (Kamala et al. 1999).

As known, boron compounds have several great advantages for application as wood preservatives and fire-retardants, including a broad spectrum of activity against insects and fungi, low mammalian toxicity, low volatility, and absence of color and odour (Yalınkılıç et al. 1999). Due to their hygroscopic character, they may affect the

dimensional stability of wood. Yalınkılıç et al. (1995, 1999) reported that the addition of water repellent polymers or hydrophobic reagents to boron solutions could reduce this effect.

The changes of physical properties caused by the preservative treatment of wood and the chemical and physical mechanisms of these changes have been studied by numerous researchers for a long time. Two major reviews have been published (Winandy 1988; LeVan and Winandy 1990). The effects of boron treatments on mechanical, biological, and dimensional properties of wood and wood based materials have been widely investigated (Laks et al. 1988, Dimri and Shukla 1991, Hashim et al. 1992, Dimri et al. 1992, Laks and Manning 1995, Yalınkılıç et al. 1999). However, little is known about the strength properties of LVL treated with wood preservative in general. Kamala et al. (1999) indicated that LVL of rubber wood can be compared with teak in many properties. On the other hand, Militz (1991) determined that the diffusion of the borate in laminated beams made from spruce, pine and larch was poor when the borate preservative was applied as rod. Gomben and Gorman (1994) reported that the penetration was inhibited in the face ply direction, apparently due to glue-lines and, incising the face plies will likely be required for lodgepole pine LVL treated with pentachlorophenol. These studies suggest that the impregnation of each veneer individually before the manufacturing of LVL panels may be an appropriate way to treat LVL material.

The aim of the present research was to examine changes in the mechanical properties of LVL obtained from beech veneers treated with boric acid.

2 Material and Method

2.1 Material

Beech (*Fagus orientalis* Lipsky) veneers (2.1 mm thick) obtained by rotary cutting at a plywood mill in industrial conditions were used in production of LVL. Test and control specimens were obtained from the outer part of the same log. Veneers were dried up to 6–8% moisture content by using a veneer dryer.

Dipping method was applied to the veneers for impregnation. For that reason, a tank with 50 cm × 30 cm × 55 cm dimensions was prepared and the interior part of the tank was divided at equal intervals to provide equal amounts of impregnation solution to each veneer. Before impregnation, veneers were conditioned at 20 °C until the moisture content of the samples reached 7%, and weighed. Veneers were dipped into 5% aqueous solution of boric acid for 20 minutes. After impregnation, the veneers were subjected to a second drying process in industrial conditions, then conditioned to 7% moisture content again and re-weighed. Net uptake of boric acid was calculated from the difference between the last weight and the initial weight. The mean retention of veneers was found as 11.5 kg/m³ (min. 8.6, max. 13.2). Three replicate panels with 0.72 g/cm³ density were produced for both test and control groups.

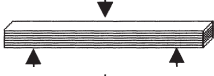
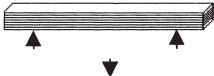
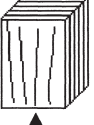
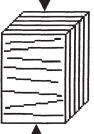
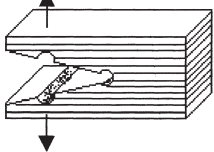
47% phenol formaldehyde glue resin was used for producing LVL. Before the gluing process, the veneers were stored in a acclimatization chamber until they had reached about 7% moisture content. Production of LVL was conducted in laboratory conditions. The adhesive mixture was applied on single bonding surfaces of veneers at approximately 160 g/m² by using a cylinder gluing machine. After the gluing process, nine 50 cm × 50 cm veneers were pressed with the grain directions of all veneers being the same. The applied pressure, temperature and duration were 12 N/mm², 140 °C and 15 minutes, respectively.

2.2 Method

Mechanical properties summarized in Table 1 were determined on LVL produced from beech veneer impregnated with boric acid. Thirty replicate specimens were used for each test method.

To evaluate the changes in mechanical properties of the untreated and impregnated beech LVL panels statistically, F-test was first used for each variable to test if variances were different at 0.05 significance level. Depending on the test result, the means were then compared with equal-variance t-test or unequal-variance t-test using SPSS statistical software package (Özdamar 1999).

Table 1. Mechanical tests applied to LVL.

Test	Standard	Dimensions of sample (in cm)	Shape of sample
Static bending strength in grain direction (MOR)	DIN 52186	$2 \times 30 \times$ thickness of LVL	
Modulus of elasticity in static bending (MOE)	DIN 52186	$2 \times 30 \times$ thickness of LVL	
Compression strength in longitudinal direction	DIN 52185	$2 \times 3 \times$ thickness of LVL	
Compression strength in tangential direction of veneers	DIN 52192	$2 \times 3 \times$ thickness of LVL	
Splitting strength in transverse direction of board	According to Kollmann (1968, p. 331)	$2.5 \times 4.5 \times$ thickness of LVL	
Pull-out of screw strength perpendicular to surface	DIN EN 320	$7 \times 7 \times$ thickness of LVL	-
Hardness perpendicular to surface	According to Brinell	$5 \times 5 \times$ thickness of LVL	-

3 Results

The mean values (\bar{x}) of mechanical properties investigated and the related statistics are summarized in Table 2.

As can be seen in Table 2, the mean strength values obtained from static bending test (MOR) were 111.5 N/mm^2 for untreated panels and 105.8 N/mm^2 for treated panels with boric acid. According to the t-test, the effect of boric acid on static bending strength was statistically significant but less significant in practical use of LVL. The modulus of elasticity (MOE) values of the untreated panels were also higher than those of treated panels. However, no statistically significant difference was found between the untreated and the treated LVL panels.

The mean values of compression strength parallel to grain of the untreated and the treated panels were calculated as 50.7 N/mm^2 and 51.4 N/mm^2 , respectively. Boric acid treatment had no remarkable effect on compression strength in longitudinal direction of LVL. However, compression strength in tangential direction of veneer was significantly affected by the treatment. The mean values obtained for the untreated and the treated panels were 18.6 N/mm^2 and 12.0 N/mm^2 , respectively. The differences between the mean values of the untreated and the treated panels were statistically significant.

The mean values of splitting strength of the untreated and the treated LVL panels perpendicular to grain and glue line were 0.343 N/mm^2 and 0.144 N/mm^2 , respectively. The effect of boric

Table 2. Mechanical test results of LVL panels ($n^a=30$).

Mechanical properties	Untreated panels		Panels treated with boric acid		% changes	F-test for variances p-value	t-test for means p-value
	\bar{x}	sd ^{b)}	\bar{x}	sd			
Static bending strength in grain direction (N/mm ²) (MOR)	111.5	10.62	105.8	6.42	-5.12	0.0123	0.0298
Modulus of elasticity in static bending (N/mm ²)	17230	2405	16584	1845	-3.75	0.1837	0.27
Compression strength in longitudinal direction (N/mm ²)	50.7	1.59	51.4	2.3	+1.38	0.0489	0.20
Compression strength in tangential direction of veneers (N/mm ²)	18.6	1.88	12.0	0.56	-35.48	0.0005	1.16 E-20
Splitting strength in transverse direction of board (N/mm ²)	0.343	0.036	0.144	0.026	-58.02	0.1029	2.7 E-32
Pull-out of screw strength perpendicular to surface (N)	1676	137.9	2100	177.1	+25.30	0.1837	8.37 E-15
Brinell hardness perpendicular to surface (N/mm ²)	21.4	4.49	23.5	3.76	+9.81	0.3727	0.0557

^{a)} Number of samples

^{b)} Standard deviation

acid treatment on splitting strength was statistically significant according to the t-test.

When the Brinell hardness values perpendicular to grain and glue line were compared, the mean value for the treated panels (23.5 N/mm²) was higher than that for the untreated panels (21.4 N/mm²). According to the result of t-test applied for this variable, the significance level obtained for two average values (0.056) was found a bit higher than the chosen significance level (0.05). Therefore, it can be stated that there was a difference between these two average values with 94.4% confidence.

The mean value of screw pull-out strength of LVL panels perpendicular to grain and glue-line were 2100 N and 1676 N for the panels produced with and without boric acid, respectively. This difference was also significant at 8.37 E-15 significance level according to the t-test.

4 Discussion

Moisture content and temperature both affect mechanical properties; these effects are pronounced when LVL is treated with preservatives and/or fire-retardant chemicals like boric acid (Winandy 1988). On the other hand, the effect of preservatives in strength parameters is a complicated research problem. In fact, the effect of the examined preservative becomes extremely hard to determine in a reliable way because of the natural variability in wood strength caused by structural differences (Wazny and Krajewski 1992). In this study, these effects were minimized by using veneers which were obtained from the same log and had same properties for structural aspects.

When wood is treated with inorganic salts, such as boric acid, diammonium phosphate, ammonium sulfate, these chemicals alter the pyrolysis of wood, increasing the amount of char and reducing the amount of volatile, combustible materials.

Acidic fire-retardants can catalyze dehydration of glucose units and depolymerization of cellulose (LeVan and Winandy 1990). Thus, they cause a loss in strength properties due to wood fiber network degradation. In our study, reductions compared with the untreated specimens in MOR and MOE were 5.1% and 3.8%, respectively. These reductions are of little practical consequence and consistent with the adjustment factors recommended by the National Forest Products Association in USA (adjustment factor is 0.85 for MOR and 0.90 for MOE according to NFPA specification) (Winandy 1988). These reduction values are also more reasonable than those obtained in several previous studies varying between 13 and 34% for MOR and 5 and 10% for MOE for plywood treated with boron compounds (Winandy 1988, LeVan and Winandy 1990). The MOR and MOE values of the beech LVL were 105.8 N/mm² and 16584 N/mm², respectively.

The most negative effect of the treatment was found in the results for splitting strength, which showed a 58% reduction. In splitting strength test, wood cells are being pulled apart at right angles to their length. Splitting strength is extremely variable and is often avoided in discussion on wood mechanics. On the other hand, the boric acid attacks amorphous regions of the wood cell wall in a manner similar to water, forcing the microfibrils apart and leading to swelling of the material. The fact that splitting strength was decreased in LVL treated suggests that the boric acid solution swells the intrapolymeric spaces, reduces cross-linking and, thus, reduces strength (Winandy and Rowell 1984, Hashim et al. 1992).

In addition, the boric acid treatment affected the compression strength in tangential direction of veneers negatively. This strength was reduced in a ratio of 35%. When the veneers treated with boric acid are glued with phenol formaldehyde, which is an alkali, the glue-line of LVL becomes more elastic. In addition, bond strengths of PF-bonded waferboard containing biologically-effective levels of sodium borates or boric acid are being reported to be unacceptably low. This is most likely due to gelling of the phenolic adhesive by the borate before the glue droplet can wet, transfer to, and penetrate an opposite wood surfaces (Laks and Manning 1995). Furthermore, acids can catalyze the dehydration of a glucose unit

and decrease the degree of polymerization (DP) of cellulose (LeVan and Winandy 1990). Because of these probable reasons, compression strength perpendicular to the grain was reduced.

In contrast to compression perpendicular to grain, compression strength in longitudinal direction of the LVL treated with boric acid increased about 1.4% compared with the untreated panels. As known, compression strength parallel to the grain is solely an axial property. For that reason, the reduction in DP of cellulose chain due to the acid dehydration phenomenon has no great effect on that strength. Generally, it can be said that compression strength in longitudinal direction is not importantly affected by wood preservation treatment (LeVan and Winandy 1990, Wazny and Krajewsky 1992). For example, Wazny and Krajewski (1992) suggested that CCA (chromated copper arsenate) and NaPCP (sodium pentachlorophenol) preservatives did not have any practical effect on the compression strength parallel to the grain of radiata pine.

The Brinell hardness and pull-out of screw strength values of the LVL treated with boric acid were significantly higher than those of the untreated panels. Increase in hardness and pull-out of screw strength values was 9% and 20%, respectively. Like the preservative salts, fire-retardant salts also precipitate in the cell cavity and the cell wall (Winandy and Rowell 1984). Precipitation of boric acid in the cell lumens and the cell wall gives a weight percent gain to each veneer forming LVL. Especially, the upper layers of the LVL, on which hardness and pull-out of screw tests were applied, are expected to have a resistance to indentation. In addition, crystal formation of boric acid within the wood cell probably reinforced this resistance of the upper layers of LVL (Draganov 1968). The same factors possibly tend to show the same effects on screw pull-out strength value for increase. Investigating a similar subject, Johnson (1979) reported that the boric acid treatment did not effect the lateral bearing strength of lumber-plywood joints. Kamala et al. (1999) determined the pull-out of screw strength value as 3880 N for rubber wood LVL treated with fixed type preservatives. However, the obtained value 2100 N in our study did not come close to the screw pull-out strength of rubber wood LVL.

The use of laminated veneer lumber is expected to increase particularly in the curvy portions of wooden constructions. On the other hand, for some types of residential and non-residential constructions, building codes require that lumber and plywood have to be treated with fire-retardant chemicals (Winandy 1988). All these situations are valid for LVL materials also. Boric acid treatment of veneers used in producing of LVL had no effect on the average MOE, compression strength parallel to grain, Brinell hardness and pull-out of screw strength perpendicular to the surface; but it reduced average static bending strength, compression strength and splitting strength perpendicular to grain.

References

- Dimri, M.P. & Shukla, K.S. 1991. Study on the effect of wood preservatives on the glue bond strength of plywood. *Van Vigyan* 29(1): 35–39.
- , Shukla, K.S. & Kumar, S. 1992. Further study on the effect of wood preservatives on the glue bond strength of plywood. *Journal of Timber Development Association* 38(2): 14–18.
- Draganov, S.M. 1968. Fire retardants in particleboards. In: *Proceedings of Second Washington State University Symposium on Particleboard*, March 1968. Washington State University, Pullman, Washington, USA.
- Gomben, P.C. & Gorman, T.M. 1994. Treatability of lodgepole pine laminated veneer lumber. *Forest Products Journal* 44(2): 39–41.
- Hashim, R., Dickinson, D., Murphy, R. & Dinwoodie, J. 1992. Effect of vapour boron treatment on mechanical properties of wood based board materials. The International Research Group on Wood Preservation Document No. IRG/WP/3727-92.
- Johnson, J.W. 1979. Tests of fire-retardant treated and untreated lumber-plywood nailed and stapled joints. *Forest Products Journal* 29(4): 23–30.
- Kamala, B.S., Kumar, P., Rao, R.V. & Sharma, S.N. 1999. Performance test of laminated veneer lumber (LVL) from rubber wood for different physical and mechanical properties. *Holz als Roh- und Werkstoff* 57: 114–116.
- Kollmann, F.F. & Côté, W.A. 1968. Principles of wood science and technology I. Solid wood. Springer Verlag, New York.
- Laks, P.E., Haataja, B.A., Palardy, R.D. & Bianchini, R.J. 1988. Evaluation of adhesives for bonding borate treated flakeboards. *Forest Products Journal* 38(11/12): 23–24.
- Laks, P.E. & Manning, M.J. 1995. Preservation of wood composites with zinc borate. The International Research Group on Wood Preservation Document No. IRG/WP/ 95-30074.
- LeVan, S. & Winandy, J.E. 1990. Effects of fire-retardant treatments on wood strength: a review. *Wood and Fiber Science* 22(1): 113–131.
- Militz, H. 1991. Diffusion of bifluorides and borates from preservative rods in laminated beams. The International Research Group on Wood Preservation Document No. IRG/WP/3644-91.
- Özdamar, K. 1999. Statistical data analysis with package programs (analysis with multivariables). Kaan, Inc., Eskisehir.
- Wazny, J. & Krajewski, K.J. 1992. Long-term effect of CCA and NaPCP preservatives on the compression strength of radiata pine sapwood. *Holzforschung* 46(6): 533–535.
- Winandy, J.E. & Rowell, R.M. 1984. The chemistry of wood strength. In: Rowell, R.M. (ed.). *The chemistry of solid wood*. Advances in the chemistry series 207. American Chemical Society. p. 211–255.
- 1988. Effects of treatment and redrying on mechanical properties of wood. In: Hamel, M. (ed.). *Wood protection techniques and the use of treated wood in construction*: Proceedings 47358; October 28–30, Memphis, TN. Forest Product Research Society, Madison, WI. p. 54–62.
- Yalınkılıç, M.K., Baysal, E. & Demirci, Z. 1995. [Effect of boron preservatives on hygroscopy of Douglas fir wood]. First Black Sea Forestry Congress, 23–25 Oct. 1995, Trabzon, Turkey, vol. II. p. 47–60. (In Turkish).
- , Gezer, E.D., Tkahashi, M., Demirci, Z., Ilhan, R. & Imamura, Y. 1999. Boron addition to non- or low-formaldehyde cross-linking reagents to enhance biological resistance and dimensional stability of wood. *Holz als Roh- und Werkstoff* 57: 351–357.

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