

FIRE PROPERTIES OF LAMINATED VENEER LUMBER TREATED WITH SOME FIRE RETARDANTS

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ABSTRACT

The objective of this study was to determine fire properties of laminated veneer lumber (LVL) prepared from beech (*Fagus orientalis* Lipsky) veneers treated with some fire retardants. Boric acid (BA), borax (BX), and di ammonium phosphate (DAP) were used as impregnation chemicals, which are the most commonly used fire retardants in wood preservation industry. Tanalith-C 3310 was also used for comparison. Laminated veneer lumbers were manufactured using the melamine formaldehyde (MF) and phenol formaldehyde (PF) adhesives. Fire test method was performed in three stages: flame stage, without flame stage, and glowing stage.

Results indicated that the lowest temperature for flame stage, without flame stage, and glowing stage were obtained for the specimens glued with MF and treated with DAP and (BA-BX) mixture.

The lowest mass loss was found for the specimens glued with MF and treated with DAP and (BA-BX) mixture. Tanalith-C 3310 didn't improve fire resistance of the LVL specimens.

KEY WORDS: laminated veneer lumber, fire retardants, Tanalith-C 3310, fire properties

INTRODUCTION

Wood is preferably used for residential construction since ancient times, because of its natural beauty and excellent properties, such as, high specific strength, heat insulation, ease to handle, and process (Su 1997). However, due to depletion of forest resources there is a shortage of wood required by the industry. Therefore, it is necessary to conserve wood from forests and alternative sources of wood, raw material from plantation timbers may to some extent meet the demand for industrial wood (Kamala et al. 1999, Jagadish 1991). Recently, increasing attention has been focused on the development of composite products

considering the global condition of forest resources for environmental and economical reasons (Su 1997). With the development of the wood composite technology, it is possible to use small girth logs in the form of modified, particle or layered composites. Particleboard and fiberboard are the main types of composite materials and can be substituted for wood only for certain uses and can not be considered as a total substitute for all purposes because of its certain inherent limitations (Jagadish 1991, Kamala et al. 1999). The layered composite materials vertically and horizontally glued such as laminated wood and laminated veneer lumber have been developed alternative to solid wood as these composite materials retain the structural properties of wood (Aydin et al. 2004, Kamala et al. 1999).

Carbon-based, cellulosic materials, such as wood and bio-based composites will combust, pyrolyze or burn when subjected to either radiant energy (as from a fire a short distance away) or sufficient direct heat (as from a flame in direct contact) (Slifka 1997). For wood ignition, O₂ flame source and flammable materials are necessary. However, wood has excellent natural fire resistance due to its low thermal conductivity. Charring is formed when wood is burned. In order to reduce flammability and provide safety, wood is treated with fire-retardant chemicals. In other words, the combustibility of wood may be reduced with flame-retardant or fire-retardant (Nussbaum 1988, Ellis and Rowell 1989, Mitchell 1993). Several theories have been reviewed about fire retardant's mechanisms by Browne (1958) and Le Van (1984). The most widely accepted mechanism is referred to as the chemical theory. This theory suggests that the fire retardants directly alter the pyrolysis of wood, increasing the amount of char and reducing the amount of volatile, combustible vapors. The most common fire retardant chemicals used for wood are the inorganic salts, such as di ammonium phosphate, monoammonium phosphate, zinc chloride, ammonium sulfate, borax, and boric acid. Di ammonium phosphate and mono ammonium phosphate are the oldest known fire retardant systems and they are usually included in most proprietary systems used for wood (Levan and Winandy 1990).

Borates have several great advantages as wood preservatives as well as imparting flame retardancy, providing sufficient protection against all forms of wood destroying organisms, have low mammalian toxicity and low volatility, they are moreover colorless and odorless (Hafizoglu et al. 1994, Murphy 1990, Yalinkilic et al. 1999, Drysdale 1994, Chen et al. 1997). Browne and Tang (1963) investigated that fire resistance of sodium borax, sodium chloride, potassium carbonate, aluminum chloride, and ammonium phosphate. All compounds increased the residual char weight of material. Brenden (1967) found that an increased amount of char is correlated with reduced amounts of tar. Shafizadeh (1984) tested 21 different fire retardants; phosphoric acid was the most effective in reducing the amount of volatiles and increasing the amount of residual char, followed by mono and di ammonium phosphate, and zinc chloride. Gottlieb (1956) reported that phosphorus compounds act as acid precursors, during combustion or pyrolysis; they form acids that cause selective decomposition of cellulosic material to form increased amounts of combustible volatiles. According to Baysal (1994), the weight losses and destruction time of calabrian pine wood specimens treated with a mixture of boric acid and borax were highly decreased compared to untreated control specimens in significantly levels after fire test. Yalinkilic et al. (1998) reported that douglas wood treated with a mixture of boric acid and borax (7:3; weight: weight) had a higher fire-retardant properties than sole treated with BA and BX.

The objective of the work reported here was to determine fire performance of LVL manufactured from beech wood glued with MF and PF adhesives and treated with some fire retardant chemicals.

MATERIAL AND METHODS

Preparation of test specimens

The beech (*Fagus orientalis* Lipsky) used in the study was obtained from the Meryemana Research Forest in Trabzon Province of Turkey. The general principles of the ISO 4471 (1982) standard were complied while felling the trees. Beech veneers with thickness of 2.6 mm which were used in the manufacture of LVL, were obtained by rotary cutting in a plywood mill at industrial conditions.

Melamine formaldehyde (MF) and phenol formaldehyde (PF) adhesives were used in the bonding of the laminations on top of each other. These adhesives are usually preferable for the assembly or furniture production in the woodworking industry. In essence, MF is generally preferred as melamine-urea or melamine-phenol formaldehyde mixtures in hardwood plywood: end-jointing and edge-gluing of lumber, and scarf joining softwood plywood. Before the bonding process, the veneers were stored in a climatization chamber until they reached a moisture content of about 12 %. The MF and PF adhesives were applied on a single bonding surface of veneers at approximately 200 g/m² by using a roller coater. After the gluing process, veneers were pressed under 2,5 kgf/cm² at 110°C for 4 min. Some physical properties of adhesives used in this study are given in Tab. 1.

Tab. 1: Some physical properties of adhesives

Adhesives	pH	Viscosity mPa.	Time to solidity at 100°C -110°C	Gel time at 20°C
Phenol formaldehyde	7.5	13.000±2.000	2-4 min.	15-20 min.
Melamine formaldehyde	9.0	12.000±3.000	2-3 min.	15-20 min.

Preparation of the chemicals solution

Aqueous solutions of boric acid (BA), borax (BX), and di ammonium phosphate (DAP), dissolved in distilled water to a concentration of 5 %. Then, wood specimens were impregnated with chemicals according to ASTM D 1413-76 (1976). A vacuum desiccator used for the impregnation process was connected to a vacuum pump through a vacuum trap. Vacuum was applied for 60 min. at 760 mHg⁻¹ before supplying the solution into the chamber followed by another 60 min. at 760 mmHg⁻¹ diffusion period under vacuum. Weight percent gain (WPG) (% , w/w) due to chemical load was calculated from the following equation:

$$\text{WPG} = \frac{W_{of} - W_{oi}}{W_{oi}} \times 100 \quad \%$$

Where; W_{oi} is the oven-dried weight (g) of a wood specimen before impregnation, and W_{of} is the final oven-dried weight (g) of a wood specimen after impregnation.

Impregnation procedure is given in Tab. 2. Five replicates were used for each variation.

Tab. 2: Impregnation procedure

Chemicals	Concentration %	Mixture ratio weight/weight	pH	Density g/ml
BA	5	100	4.56	1.030
BX	5	100	9.05	1.035
(BA-BX)	5	50/50	7.91	1.030
(DAP) - (BA-BX)	5	50/(25/25)	5.08	1.110
Tanalith-C 3310	^a	100	2.48	1.700

^a Viscosity of package

Fire test method

The test specimens were cut to 13 x 13 x 76 mm (radial by tangential by longitudinal) according to the procedure of ASTM E 160-50 (1975). Specimens were conditioned at $27 \pm 2^\circ\text{C}$ and 30-35 % relative humidity to the targeted equilibrium moisture content of 7 % prior to fire test. Twenty four specimens were stowed to make 12 layers which shaped square prism (Fig. 1). Heating flame was sourced to a LPG tank controlled by a sensitive bar-gauged valve. Flame was balanced to the standard height before fire test samples' frame. Then fire test method was performed (flame stage (FS), without flame stage (WFS), and glowing stage (GS)) according to ASTM E 160-50. Temperatures were recorded at the combustion column by thermocouples at 15, 30, and 30 second intervals for combustion with a flame stage, without flame stage, and glowing stage respectively. The mass losses of test specimens after fire test were calculated from the following equation:

$$\text{Mass losses} = \frac{W_{\text{bf}} - W_{\text{af}}}{W_{\text{bf}}} \times 100$$

Where; W_{bf} is the weight (g) of a wood specimen before fire test, and W_{af} is the weight (g) of a wood specimen after fire test. Five replicates were used for each variation.

Evaluations of fire test results

Fire test results were evaluated by a computerized statistical program composed of analysis of variance and following Duncan tests at the 95 % confidence level. Statistical evaluations were made on homogeneity groups (HG), of which different letters reflected statistical significance.

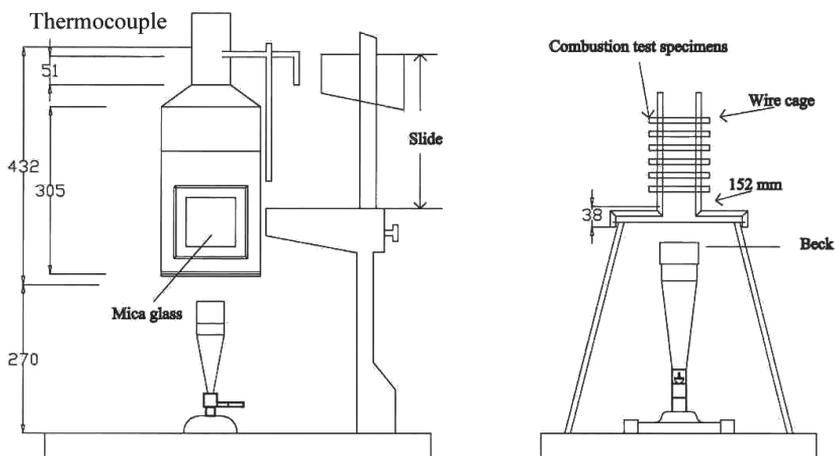


Fig. 1: Combustion test apparatus

RESULTS AND DISCUSSIONS

Weight percent gain and mass loss

The highest WPG of LVL specimens were obtained impregnated with Tanalith-C3310 as 16.17 %. Weight percent gain levels of sole BA and BX were higher than a mixture of BA and BX. The lowest WPG of LVL specimens resulted in treated with a mixture of BA and BX as 2.04 %. Weight percent gain levels of LVL specimens are given in Tab. 3. Nussbaum (1988) investigated that the effect of low concentration fire retardant impregnations on wood charring rate and char yield. Results showed that at 1 % retention, no significant effects were obtained. However, the char yield was increased by 100- 150 % at 15 % retention levels. Mass losses of LVL manufactured from beech wood are given in Tab. 4. After combustion, the lowest mass losses were recorded with the LVL glued with MF and treated with mixtures of DAP and (BA-BX) (33 %).

Tab. 3: Weight percent gain (WPG) of fire retardants

Chemicals	Concentration %	Mixture ratio Weight/Weight	WPG(%) Mean
BA	5	100	3.21
BX	5	100	3.39
(BA-BX)	5	50/50	2.04
(DAP) - (BA-BX)	5	50/(25/25)	2.81
Tanalith-C 3310	^a	100	16.17

^a Viscosity of package.

Tab. 4: Mass losses of LVL after fire test

Treatment chemicals	Mass losses (%) (Mean \pm SD*)
PF-Control	73.4 \pm 6.3
PF-BX	65.8 \pm 5.6
PF-BA	77.4 \pm 9.3
PF-(BA+BX)	75.5 \pm 4.4
PF- (DAP) –(BA-BX)	60.8 \pm 5.7
PF-(Tanalith-C 3310)	76.1 \pm 7.2
MF-Control	81.0 \pm 8.4
MF-BX	73.0 \pm 5.3
MF-BA	76.0 \pm 3.6
MF-(BA+BX)	73.8 \pm 5.5
MF-(DAP)-(BA-BX)	33.0 \pm 2.9
MF-(Tanalith-C 3310)	65.0 \pm 4.9

*Standard deviation

Baysal (2003) reported that *Fagus orientalis* wood specimens treated with a mixture of BA and BX (7:3; w/w) lost around 68 % mass during combustion. Yalinkilic et al. (1998) found that douglas fir specimens treated with a mixture of BA and BX (7:3; w/w) lost around 58 % mass during combustion. Therefore, mixture of DAP and (BA-BX) treatment of LVL glued with MF resulted in less mass losses compared to those of mentioned above studies.

Temperature records at the combustion column during with and without flame stage, and glowing stage

Temperatures were steadily recorded at the combustion column by thermocouple at a 15, 30, and 30 second intervals, for the combustion with and without flame stage and glowing stage respectively. Tab. 5 contains the recorded temperature degrees in Celsius of with and without flame stage and glowing stage.

Fire retardants treatment had lower heat release rate at almost all combustion stages indicating inhibitors effects of fire retardants on combustion. Holmes (1974) reported that treated wood under fire has a decreased rate of initial heat contribution. This means that the spread of fire from treated wood to nearby combustibles is slow. The lowest heat release at the combustion with and without flame stage, and glowing stage were obtained with 210 °C, 240, and 136 °C for LVL specimens glued with MF and treated with mixtures of DAP and (BA-BX), respectively. Therefore, DAP and (BA-BX) mixture treatment for these trials of combustion had a reducing effect of heat release rate. Achieved lower temperature records also indicate the fire retardance effect of DAP and (BA-BX) on combustion when combined together. Because, generally sole BA and BX mixture treatment yielded higher heat release compared to that of DAP and (BA-BX) mixture treatment. Baysal (1994) found that the heat release for Calabrian pine wood treated with boric acid was 165.5 °C at the flame stage, 290.5 °C for without flame stage and 118.0°C for glowing stage. It was seen that wood specimens treated with Tanalith- C 3310 and

glued with PF had the highest heat release without flame stage with average of 788°C and 745°C respectively. Therefore, it seems that it is necessary to take some further precautions for this commercial preservative when it is used alone.

Tab. 5: Temperature records at during flame stage, without flame stage (TFS and TWFS) and glowing stage (TGS)

Treatment chemicals	TFS (°C)		TWFS (°C)		TGS (°C)	
	Mean	HG*	Mean	HG	Mean	HG
PF-Control	678	A	618	E	143	BC
PF-BX	590	CD	727	BC	157	BC
PF-BA	643	ABC	655	D	182	BC
PF-(BA+BX)	663	AB	695	CD	198	BC
PF- (DAP) –(BA-BX)	600	BCD	715	BCD	160	BC
PF-(Tanalith-C 3310)	545	DE	788	A	254	A
MF-Control	623	ABC	721	BCD	154	BC
MF-BX	602	BCD	716	BCD	180	BC
MF-BA	596	CD	721	BCD	184	BC
MF-(BA+BX)	548	DE	768	AB	210	AB
MF-(DAP)-(BA-BX)	210	F	240	F	136	C
MF-(Tanalith-C 3310)	502	E	705	BCD	164	BC

* Homogeneity groups obtained by statistical analysis with similar letters reflecting statistical insignificance at the 95 % confidence level.

CONCLUSIONS

Some limited fire properties of LVL manufactured from beech wood treated with some fire retardants were studied.

Overall the LVL specimens glued with MF and treated with mixture of DAP and (BA-BX) showed the highest fire resistance. Generally, boric acid and borax mixture treatment was combined with a mixture of DAP to enhance fire resistance of wood compared to that of sole BA and BX mixture treatment. Boron compounds increased fire properties of LVL specimens in some extent. Tanalith-C 3310 did not show fire retardant effect.

Boric acid and borax mixtures have some efficacy in retarding flame spread on wood surfaces. In addition to the usual char-forming catalytic effect, they have a rather low melting point and form glassy films when exposed to high temperatures in fires (Nussbaum 1988). Borax tends to reduce flame spread but can promote smoldering or glowing. On the other hand, boric acid suppresses smoldering but has little effect on flame spread. Therefore, these compounds are normally used together (Le Van and Tran 1990). Their combinations with DAP can be a gate for an increased fire resistance of LVL specimens.

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