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FIRE PERFORMANCE OF LVL PANELS TREATED WITH FIRE RETARDANT CHEMICALS

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ABSTRACT

In this study we evaluated the combustion properties of laminated veneer lumber (LVL) panels treated with various fire retardant chemicals. Commercially manufactured rotary-cut beech wood (*Fagus orientalis* L.) veneers were treated with a borax-boric acid mixture, monoammonium phosphate or diammonium phosphate. Based on our results the lowest combustion temperatures were observed in panels treated with diammonium phosphate (220°C), while the highest combustion temperatures were observed in panels treated with a borax-boric acid mixture (420°C). Chemically treated panels experienced less mass loss than untreated panels. Chemically treated panels could be used safely in building construction due to their improved fire performance.

KEYWORD: Fire performance, fire retardant chemicals, combustion temperature, weight loss, LVL panels.

INTRODUCTION

Wood and wood-based composites are of great importance in the furniture industry and in both residential and commercial construction. Engineered composite materials represent one of the fastest growing sectors of the wood products industry. LVL panels are structural composite materials made from veneer sheets that are bonded together with various adhesives; these panels provide an alternative to wood and other wood composites. Wood composites are used as a construction material in more than 40 percent of new residential construction in North America, with LVL serving as the primary flange material for the manufacture of I-joists. These laminated veneer lumber panels provide a substitute for solid wood while retaining the structural properties of wood (Haygreen and Bowyer 1996).

Because LVL panels are commonly used in the furniture and building industries, their combustion performance is an important consideration when choosing various types of thin overlays, or finishes, to apply to the surface of fire retardant treated LVL panels. As markets for structural LVL panels expand, these products are being used in wider and more demanding applications. Fire-retardant-treated (FRT) LVL panels are being used increasingly for both roofing and exterior siding. Now, FRT moulded wall panels are being produced such that the composite comprises both the skin and the structural elements.

It is well known that the fire performance of wood and wood composites can be significantly improved by chemical treatments, thereby widening their utilization options (Ayrilmis et al. 2007, Kartal et al. 2007). FRT wood products provide a viable alternative to traditional noncombustible materials in cases where a higher level of fire safety is required. The most common fire-retardant chemicals used to treat wood and wood based panels are inorganic salts, phosphoric acid (PA), monoammonium phosphate (MAP), diammonium phosphate (DAP), ammonium sulfate, nitrogen, zinc chloride (ZnCl), and boron compounds such as borax (BX) and boric acid (BA). Of these, phosphates and boron compounds are among the oldest known fire-retardants, and are usually included in most proprietary systems used for wood. Due to their effectiveness as a preservative, and relatively low impacts on the mechanical properties of wood, boron compounds are often preferable to other fire retardants (Anonymous 1999, Lebow and Winandy 1998, Levan and Tran 1990, Winandy 1997). Additionally, boron compounds are among the safest compounds in current use; no fatalities or other harmful effects have been associated with their use as a fire retardant, or in other industrial applications.

Researchers have investigated various fire retardants for use with LVL panels. Ozciftci and Okcu (2008) investigated combustion performance of LVL panels treated with zinc chloride and BX. Uysal (2005) evaluated the effects of DAP, aluminium sulphate, potassium carbonate, calcium chloride, and zinc chloride on fire resistance of LVL bonded with polyvinyl acetate and phenol formaldehyde resins. Combustion performance of LVL treated with BX, BA, BX/BA, imersol-aqua, and timbercare-aqua has been determined by Keskin et al. (2009), and physical, mechanical, and fire properties of oriented strandboard (OSB) panel faced with FRT veneers has been evaluated by Ayrilmis et al. (2007).

Keskin (2009) examined influence of impregnation chemicals on the flame source combustion light intensity of the LVL. It was stated that boric acid showed decreasing impact on the flame source combustion light intensity of the samples. Kurt and Mengeloglu (2008) studied effects of BA/BX treatment on mechanical and combustion properties of LVL made from hybrid poplar. They found that modulus of rupture and combustion properties of LVL improved by BA/BX treatment. Kurt (2005) investigated the effects of BA/BX addition on physical, mechanical, and combustion properties of wastepaper boards. It was reported that physical and combustion properties of wastepaper boards improved and both modulus of rupture and modulus of elasticity values decreased with BA/BX modification.

In previous studies we discussed surface roughness (Dundar et al. 2008), dimensional stability performance (Dundar et al. 2009), and wettability characteristics of LVL panels (Ayrilmis et al. 2009). The purpose of this paper is to document the effects of fire retardant chemical treatments on the fire performance of LVL panels; specifically we will examine combustion temperature and weight loss.

MATERIAL AND METHODS

Rotary cut veneer obtained from Beech (*Fagus orientalis* Lipsky) logs at Kurogullari Plywood Company in Istanbul, Turkey were used to make LVL panels under laboratory conditions. The Beech was grown naturally in Northeast Turkey and air-dried to a density of 0.63 $g.cm^{-1}$, this material is well suited to the manufacture of veneer, plywood, and LVL panels. Each veneer sheet was 500 by 500 by 2.7 mm thick. The veneer was nearly defect-free to reduce variability in mechanical properties which could result from random defects in the interior of the veneer. These were then transported to the Wood Composite Panels Manufacturing Laboratory, Department of Forest Products Engineering at Istanbul University. The sheets were kept in a conditioning chamber until they equilibrated to a moisture content of seven percent.

Fire retardant chemical treatments

Three chemicals were used to treat the veneer: (1) a 1:1 mixture of boric acid-H_3BO_3 and borax (BX)-$Na_2B_4O_7.10H_2O$, (2) monoammonium phosphate-$NH_4H_2PO_4$, and (3) diammonium phosphate-$(NH_4)_2HPO_4$, (from Eti Mine corp., Ankara Turkey). The typical chemical composition of boric acid: borax (1:1), MAP, and DAP is shown in Tab. 1.

Tab. 1: Typical composition of borax, boric acid, monoammonium phosphate, and diammonium phosphate.

Chemical	Component	Amount (%)
Borax	B_2O_3	36.4
	Na_2O	16.4
	Purity	99.9
Boric acid	B_2O_3	56.2
	Purity	99.9
Monoammonium phosphate	P_2O_5	61.0
	N	12.0
	Purity	99.9
Diammonium phosphate	P_2O_5	53.0
	NH3	25.0
	N	20.8
	Purity	99.9

The veneers were pressure impregnated with the fire retardant chemicals using a full-cell pressure process. Veneer samples were placed in a vacuum at a pressure of 650 mm Hg for 30 minutes, the chemicals were added, and a pressure of 1.1 $N.mm^{-2}$ was then applied for 60 minutes. Concentration of the chemical solutions was adjusted to provide an average retention of 57 $kg.m^{-3}$.

Manufacture of LVL panels

Following the impregnation, the treated veneer sheets were re-dried in a laboratory oven. The sheets were then re-conditioned at 20°C and 65 percent relative humidity before being used to manufacture the LVL panels. A total of 12, 5-ply, 10-mm-thick experimental panels were manufactured from the veneer sheets, three for each chemical treatment and three for control purposes. An exterior phenol formaldehyde resin with 47 percent solid content was applied to single bonding surfaces of the veneers at a rate of 200 $g.m^{-2}$. The individual veneers were then assembled with the grain of all veneers running horizontally along the billet and hot pressed under 1.5 $N.mm^{-2}$ of pressure at a temperature of 140°C for 15 minutes in a laboratory hot press. The resulting LVL panels were allowed to cool for 48 hours before being cut into individual samples. LVL panels were conditioned at 20°C and 65 percent relative humidity for three weeks before testing.

Determination of fire performance

Fire testing was carried out according to ASTM standard E 160–50 (ASTM 1976). Each group of samples was weighed prior to testing and placed on a wire stand. Each stand, with samples, was placed vertically in relation to the other stands. Samples were exposed to a 25 ± 1.3 cm flame, under a gas pressure of 0.5 $kg.cm^{-2}$ for three minutes, after which time the flame was extinguished and the samples were allowed to continue to combust. Temperature changes during combustion were determined using a thermometer. This experimental setup can be seen in Fig. 1.

Fig. 1: Experimental set up.

Percent weight loss for the test specimens was determined using the following formula:

$$\text{Weight loss} = \{(W_i - W_f) / W_i\} \times 100$$

where: W_i - initial weight (g) of the specimens,
W_f - final weight of the specimens after combustion testing procedure.

RESULTS AND DISCUSSION

The average combustion temperatures for treated and untreated samples can be seen in Tab. 2. Duncan test results indicated that combustion temperatures of the LVL panels treated with fire retardant chemicals were significantly lower than those of the untreated panels at p = 0.05 level.

Tab. 2: Average combustion temperatures of the LVL panels.

Chemical Type	Combustion Temperature (°C)
DAP	220.9 A
MAP	262.0 B
BX/BA	420.5 C
Control	448.8 D

Groups with same letters in column indicate that there is no statistical difference ($p<0.05$) between the samples according to the Duncan's multiply range test.

Of the treated panels, the highest combustion temperatures, 420.5°C, were observed in panels with BX/BA. The lowest values observed, 220.9°C, were seen in panels treated with DAP. Untreated panels reached a temperature of 448.8°C. These results demonstrate the improved combustion performance of panels treated with fire retardant chemicals.

Of the fire retardant chemicals evaluated, the most effective substance in reducing the combustion temperatures in LVL panels was DAP, followed by MAP and BX, respectively. The reasons for these differing levels of effectiveness could include differing chemical compositions and mechanisms of action for each treatment. Rowell (2005) stated that wood treated with ammonium phosphate is the most effective in both reducing the quantity of volatile products and the temperatures where these products are formed. Ammonium phosphate almost eliminates the glowing exotherm. Lee et al. (2004) determined oxygen index levels of plywood panels treated with various fire retardant chemicals. The oxygen index levels of the panels obtained from DAP were higher than those of treated panels with BX/BA. This is consistent with our findings considering highly flammable materials have a low oxygen index values and less flammable materials have high index values (White 1979). Ayrilmis et al. (2007) studied the fire performance of OSB panels with FRT veneers. They used BX/BA, DAP, MAP, and lime water as fire retardants. It was reported that the panels faced with veneer treated with BX/BA had the least impacts on initial peak heat release rate and had the least effect on the mass loss rate. Uysal (2005) reported that DAP had the most effective fire retardant chemical in LVL bonded with polyvinyl acetate and phenol formaldehyde resins. DAP and MAP alters thermal decomposition mechanism of forest species, usually by acid catalyzed dehydration reactions (Liodakis et al. 2006).

The results obtained from the combustion tests showed that weight loss values of the LVL panels were statistically significant. All chemically treated panels generated lower weight loss values than those of untreated panels. The lowest weight loss value acquired during the tests were observed in panels treated with DAP (8.01 %) followed by MAP (10.45 %), BX/BA (62.54 %), and untreated panels (89 %). The weight loss performance of the panels was positively affected by the fire retardant chemicals. Fig. 2 shows the weight loss results of the FRT LVL panels. Rowell (2005) reported that wood material treated with boric acid had a weight loss of 81 % and borax a loss of 89 % at 500°C, higher percent losses than have been observed with phosphorus chemical treatments. Similarly, Ayrilmis et al. (2007) reported DAP to be more efficient at reducing weight loss than other fire retardant chemicals such as MAP and BX/BA.

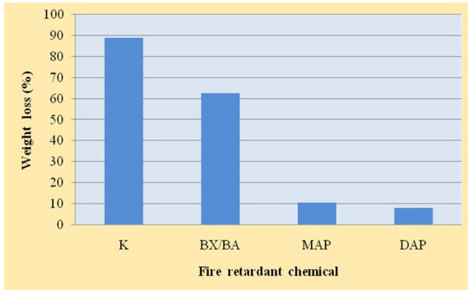

Fig. 2: Weight loss results of LVL panels.

The effectiveness of fire retardant chemicals on combustion performance of wood composite panels such as OSB, medium density fiberboard (MDF), and plywood were studied by Ayrilmis (2006). The panels treated with DAP had lower ignition times than panels treated with MAP and BX/BA. The stated reason for this was the lower melting temperature of DAP compared to MAP. The different melting behavior effects the amount and timing of combustible gas release from the surface of the panels treated with DAP. DAP creates an earlier charring reaction than MAP and BX/BA. This is in agreement with a previous study carried out by Myers and Holmes (1975).

CONCLUSIONS

The results obtained in this study showed that FRT treated panels had better fire performance than untreated panels. With regard to chemicals, the panels treated with DAP had the best fire performance, while the panels treated with BX/BA mixture had the lowest fire performance. Of the treated panels, those treated with DAP had the lowest weight loss values, while the panels treated with BX/BA had the highest weight loss values. LVL panels from FRT veneers could be used safely as engineered wood composites in building construction due to their improved fire performance.

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