Effects of various fire retardants on mechanical and fire properties of plywood

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Abstract: *Effects of various fire retardant (FR) chemicals on mechanical and fire properties of plywoods were investigated. Boron compounds such as, borax and boric acid; and phospate compounds such as, monoammonium phosphate and diammonium phospahate were used as fire retardant chemicals in the plywood panels. An exterior liquid phenol formaldehyde resin with 47% solids content was used as adhesive. The 2.2 mm thick Tetraberlina wood veneers were treated with the liquid solution of FR chemicals. The plywoods having 5-layers were produced from the treated wood veneers. The mechanical properties of the plywoods produced with treated veneers was found to be lower than that of the control group. Among the treated plywoods, The plywoods treated with borax had highest mechanical properties, followed by diammonium phosphate (DAP), monoammonimum phosphate (MAP), and, boric acid, respectively. The FR chemicals improved the fire resistance of the plywoods. The chemicals showed individually different effects related to improvement of fire resistance of the panels. For example, the OSB panels treated with diammonium phoshate were the latest ignited group (52.8 s) which were followed by the panels treated with boric acid (49.2 s), borax (44.5 s), and monoammonium phosphate (41.2 s), respectively. As compared to the control group (7.5 cm), the plywoods treated with borax (3.6 cm) had the shortest flame length after burner was turn off, followed by diammonium phosphate (4.2 cm), boric acid (5.1 cm), and monoammonium phosphate (5.8 cm).*
KEYWORDS: *WOOD-BASED PANELS, FİRE-RETARDANTS, BORON COMPOUNDS, TECHNOLOGİCAL PROPERTİES, PLYWOOD*

1. Introduction

Plywood is a wood-based panel which is widely used in construction industry. Since plywood is commonly used buildings, its fire resistance is very important to decrease fire risk and prevent to human death. It is well known that one can significantly improve the fire performance of wood-based composites by chemical treatment and thereby widen the options for their utilization. Three methods are commonly employed to provide wood-based products with improved fire-resistance and reaction-to-fire: chemical impregnation, incorporation of flame retardants into the adhesive, and flame-retardant coatings [1]. For chemical impregnation, the most widely used flame-retardant chemicals for treating wood-based products are inorganic salts that contain elemental phosphorus or boron. Boron compounds such as borax and boric acid are considered to be effective flame retardants that exert less impact on mechanical properties compared with some other flame retardant chemicals [2,3]. Phosphates such as mono- and di-ammonium phosphates, and ammonium polyphosphate are another group of fire retardants [4]. The phosphates are one of the oldest known fire-retardant systems. They are usually included in proprietary systems used for wood. For example, monoammonium phosphates (MAP) have been used in extinguishers for a long time in many places such as cars and homes, plants. Boron and phosphate compounds are widely used as FR chemicals in wood composite industry. In this study, the effect of loading level of boron and phosphate compounds on the mechanical and fire properties of plywood was investigated.

2. Materials and methods

2.1. Materials

2.1.1. Wood material

Commercial rotary veneers (2.2 mm thickness) of *Tetraberlinia bifoliolata* roundwood as raw material in the production of plywood production were supplied from a commercial plywood company, Kuris Plywood Company, in Istanbul, Turkey. The veneers without defect were sized to 490 mm x 490 mm by saw. The moisture content of the veneers was 7-8% based on the oven-dry weight of wood.

2.1.2. Resin

Phenol-formaldehyde (Polifen47) resin was supplied from Polisan The Chemical Company in Dilovası, Turkey. The mixture of of filler and extender was added into the PF resin, based on the oven-dry weight of PF resin. The dry mixture was prepared from 80 wt% calcium carbonate and 20 wt% the extender (10 wt% corn powder and 10 wt% corn starch powder)

Table 1: *Technical specifications of phenol-formaldehyde (Polifen 47) resin*

Technical specifications of PF resin	Method	Result
Density (20 °C, g/cm³)	TS 1724 ISO 675:1997/T1	1.195-1.205
Solids content (% weight)	TS EN 480-8	47±1
Viscosity (20 °C, cps)	TS 6126 ISO 2555:1998/T1	250-500
pH (20 °C)	TS EN ISO 10523	10.5-13
Free formaldehyde (% weight)	TS EN 1243	max. 1.0

2.1.3. Fire-retardant chemicals

Four powder chemicals were used in the treatments: borax, boric acid, monoammonium phosphate, and diammonium phosphate. The technical grades of the chemicals were suppled from local market in Istanbul, Turkey.

2.2. Treatment of wood veneers

Veneer samples were kept in a conditioning chamber until they reach 7% moisture content. In the next step, the specimens were soaked for 3 h in plexiglass boxes while laid horizontally 4 cm apart from each other in 3% or 6% aqueous solutions of borax ($Na_2B_4O_7$ $10H_2O$) or boric acid (H_3BO_3), or in 3% or 11% aqueous solutions of monoammonium phosphate ($NH_4H_2PO_4$) or, diammonium phosphate ($(NH_4)_2HPO_4$). The temperature of the various solutions was 60 °C during the treatment process. Each treated veneer sample was then reconditioned to 7% moisture content before plywood panels were manufactured. Before and after treatment process samples were weighted to calculate chemical retention. A total of 20 five-ply plywoods, 4 plywoods for each treatment were manufactured from the veneer with the dimension of 490 mm x 490 mm x 2.20 mm.

2.3. The production of plywood panels

After preparing commercial wood veneers with dimensions of 490 mm × 490 mm × 2.2 mm, 5-layer, the plywood panels were produced under laboratory conditions. Each type of modified UF adhesive was uniformly spread on a single bonding surface of veneers using a plastic brush at the rate of 200 g/m^2. After the glue application**,** individual sheets of the wood veneer were assembled with the same grain directions for all veneers. The plywood mats were hot pressed under 1.2 N/mm^2 of pressure at a temperature of 140 °C for 12 min in a laboratory type hot press. The densities of plywood panels ranged from 0.69 to 0.71 g/cm^3. Plywoods were conditioned at 20 °C and 65% relative humidity until the constant weight before the physical and mechanical tests. The experimental design is given in Table 2.

Table 2: *Experimental design*

Plywood code	Contentration Fire retardant solution (wt%)	Retention of fire-retardant	The number of panels produced
Control	-	-	4
Borax	6%	14.54	4
Boric acid	6%	19.37	4
Diammonium phosphate	3%	21.00	4
Monoammonium phosphate	3%	25.57	4

Fig. 2: *The plywood sample.*

2.4. Test methods

The density, and the mechanical properties such as, bending strenght, modulus of elasticity, internal bond, and bond quality of the specimens were carried out according to EN (European Norm) standards (Table 3). Fire properties such as flame height, and char area of the specimens were evaluated according to DIN (Deutsches Institut für Normung) standard (Fig. 1).

Fig. 1: *Fire test according to DIN 4102-1 standard.*

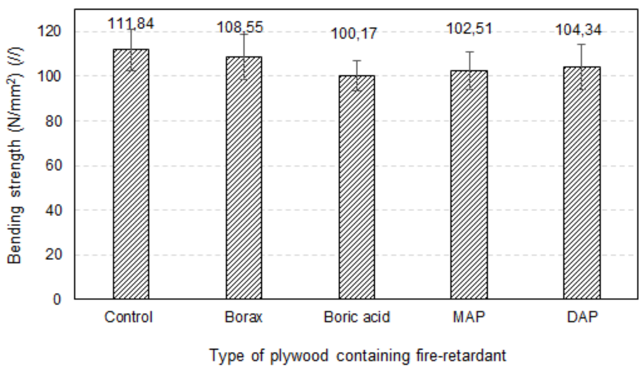
Table 3: *Test methods, the number of specimens and their size*

Test method	Standard no	Size (mm)	The number of specimens
Density	TS EN 323	50 x 50	30
Thickness swelling (24-h)	TS EN 317	50 x 50	30
Bending strength (//)	TS EN 310	250 x 50	18
Bending strength (⊥)	TS EN 310	250 x 50	18
Bending Modulus (//)	TS EN 310	250 x 50	18
Bending Modulus (⊥)	TS EN 310	250 x 50	18
Tensile-shear strength	TS EN 314	100 x 20	30
Fire resistance	DIN 4102-1	90 x 190	10

3. Results and Discussion

3.1.. Mechanical properties

The bending strength values of the plywood specimens parallel and perpendicular to the panel surface are presented in Figure 2. The panels treated with borax had highest bending strength, followed by di-ammonium phosphate (DAP), mono-ammonimum phosphate (MAP), and, boric acid, respectively. A similar trend was determined for bending modulus (Fig. 4). All the treated panel groups showed lower performance related to mechanical properties when compared to control panels group (Fig 5). The bending strength values of the plywood specimens were compared with to EN 636 (2012) standard. The FR chemical retention values of the each plywood type was different from each other. The FR retention values of plywood specimens produced using the BX, BA, MAP or DAP treated wood veneers were found to be 14.54, 19.37, 21.00, 25.57 kg/m3, respectively. Borax treated specimens showed better mechanical performance than the boric acid treated specimens. Similarly, di-ammonium phosphate treated specimens showed better performance than the mono-ammonium phospate treated specimens. The bending strength and bending modulus of the plywood specimens parallel to the fiber direction of the surface veneer were considerably higher than the bending strength perpendicular to the fiber direction of surface veneer.



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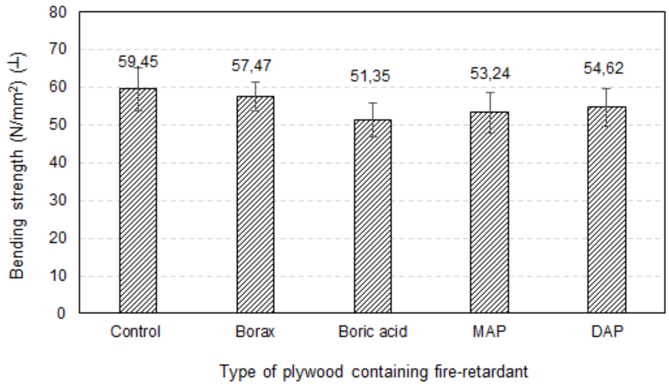

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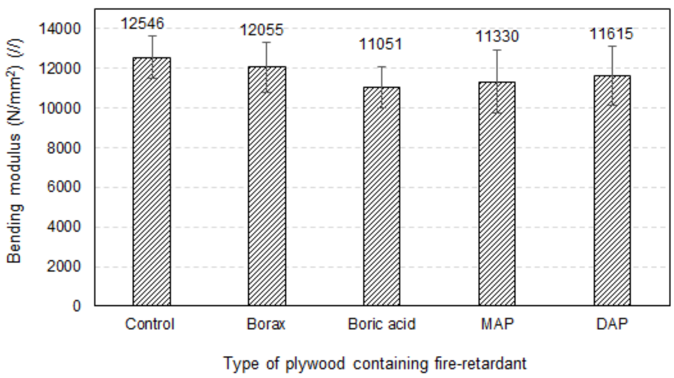
Fig. 2: Bending strength values (A: parallel and B: perpendicular to the panel surface) of plywoods



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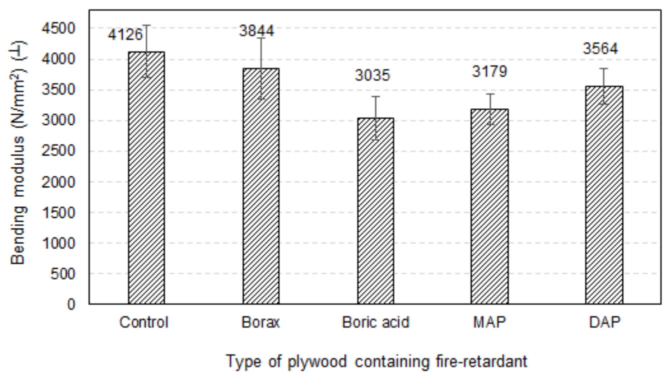

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Fig. 3: Bending modulus values (A: parallel and B: perpendicular to the panel surface) of plywoods.

The tensile shear strength of the plywood specimens shows the bond performance between the wood veneers in the plywood (Fig. 4). The bond performance between the veneers of the plywood specimens showed a similar trend to the bending properties. Although all the plywood produced using modified veneers showed lower tensile shear strength than that of the control group, they complied with the EN 314-2 (2003)standard value (minimum 1 N/mm²). The boric acid and mono-ammonium phosphate showed considerably decreased the bond performance of the plywoods as compared to borax and di-ammonium phosphate treated plywood specimens.

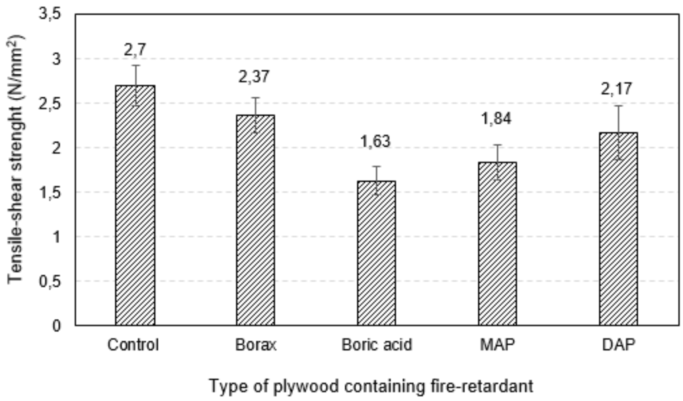
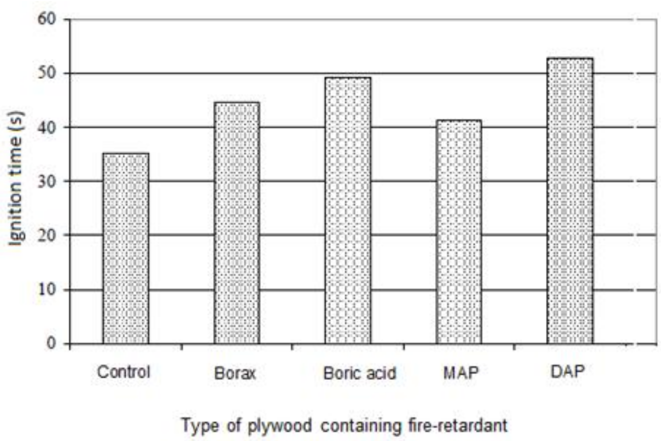


Fig. 4: *Tensile-shear strength of plywoods.*

The addition of borate to the strands with the PF resin may prevent the curing of PF resin [5]. The use of borate as a fire retardant in wood-based composite panels may cause several problems. The most critical one is related to its adverse effect on the mechanical properties of wood composites bonded with PF resin [4-7]. The main problem is related to the functional methanol groups (CH_2OH) on the PF resin molecules and their interaction with borate ions. In a previous study, Schaeffer et al. [4] determined acidic ammonium salts in both phosphate decrease the pH of theresin to a level much lower than that noted with the alkaline sodium salts. Apparently, the strength reductions in thespecimens treated with the acidic fire retardants were probably caused by a combination of accelerated resin cureand thermal decomposition [5].

3.2. Fire resistance

The ignition time and flame length of the plywood specimens are given in Figure 5. The FR chemicals improved the fire resistance of the plywoods. Their effects on the fire resistance of plywood was related to the type of FR chemical. The chemicals showed individually different effects related to improvement of fire resistance of the panels. For example, the OSB panels treated with diammonium phoshate were the latest ignited group (52.8 s) which were followed by the panels treated with boric acid (49.2 s), borax (44.5 s), and monoammonium phosphate (41.2 s), respectively. As compared to the control group (7.5 cm), the plywoods treated with borax (3.6 cm) had the shortest flame length after burner was turn off, followed by diammonium phosphate (4.2 cm), boric acid (5.1 cm), and monoammonium phosphate (5.8 cm)



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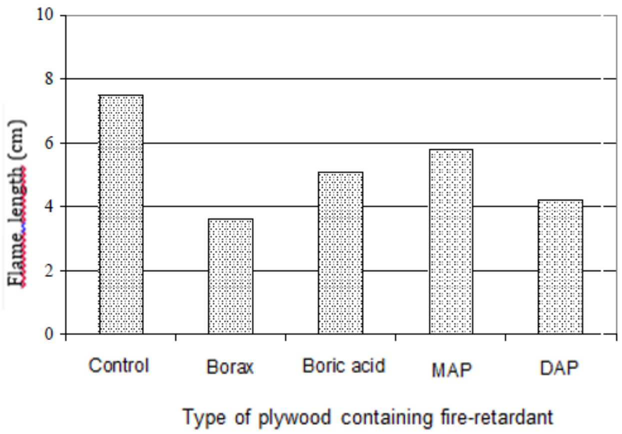

B.

Fig. 5: *Ignition time and flame length of the plywood specimens (A: Ignition time. B: flame length)*

The main reason for the later ignition time of the plywoods contaning diammonium phosphate can be explained by the fact that it more delays the release and amount of flammable gases from plywood as compared to the mono-ammonium phosphate. Furthermore, melting temperature of diammonium phosphate (155 °C) is lower than monoammonium phosphate which is more stable thermally lower than the melting temperature (190 ° C) on the sample surface by starting an early reaction. Thus, diammonium phospahte causes carbonization early and the decrease the release of flammable gases from the plywood as compared to the monoammonium phosphate [8].

4. Conclusions

The FR chemicals showed an improvement in the fire resistance of the plywood specimens. However, the mechanical properties were slighly decreased after the treatment. As compared to the boric acid and monoammonium phosphate, borax and diammonium phosphate could be used to improve the fire resistance of the OSB panels because of their relatively little effects on the mechanical properties of the panels. The boric acid and monoammonium phosphate decreased the mechanical properties of the plywood specimens more than borax and diammonium phosphate. The hot water immersion method was used to impregnate the veneers by FR chemicals in this study. If the veneers are treated with FR chemicals using vacuum/pressure method, the fire resistance of the plywood specimens can be more improved.

5. Acknowledgement

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6. References

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