The Effects of Some Fire Retardants on Physical and Mechanical Properties of HDF Panels Covered with Resin-impregnated Paper

Ferhat Özdemir,[a,]* and Ahmet Tutuş [c]

The objective of this study is to determine the effects of some fire retardants on physical and mechanical properties of the resin-impregnated paper covered high density fiberboard (HDF) panels. Fire retardants (FR) in a powder form (borax (BX), boric acid (BA), ammonium polyphosphate (APP) and alpha-x (AX) powders were used at 3%, 6% and 9%. HDF panels were produced (400x400x6.5mm). Surfaces of HDF panels were coated with resin- impregnated papers. The physical and mechanical properties of panels were investigated. The results showed that FR the addition diminished the thickness swelling (TS) and water absorption (WA) values of the panels. In addition, they also reduced the modulus of rapture (MOR), modulus of elasticity (MOE), and internal bond (IB) strengths. It was found that concentration and type of FR chemicals significantly affected the physical and mechanical properties of resin-impregnated paper covered HDF panels.

Keywords: High density fiberboard; Fire retardant; Physical properties; Mechanical properties

*Contact information: a: Department of Forest Industry Engineering, Faculty of Forestry, Kahramanmaras Sutcu Imam University, 46060 Kahramanmaras, TURKEY; *Corresponding author: ferhatozd@ksu.edu.tr.*

INTRODUCTION

Fiberboards are widely used in furniture, construction, transportation, decoration and other industries due to its moderate thickness, density, good physical and mechanical properties, and low cost. Wood and wood-based composites are susceptible to the same physical, chemical, combustion and biological deterioration as the solid wood from which they are made (Roger 2005). However, the application of medium density fiberboard (MDF) is limited in many areas because of its flammability. For this reason, treatments with fire retardants are necessary to meet the FR requirements of national standards (White et al. 1992).

The most common fire retarding chemicals used for wood and wood-based panels are: inorganic salts, such as phosphoric acid (PA), monoammonium phosphate (MAP), diammonium phosphate (DAP), ammonium sulfate, nitrogen; and boron compounds, such as borax (BX), boric acid (BA), and zinc chloride. Waterborne inorganic salts may be hygroscopic; corrosion metal fixtures in treated wood may be increased. Treatment may affect the appearance and the paint ability (occurrence of surface blooming) of the wood (Hashim 1994). Previous studies have investigated the fire retardant treatment of wood based composites (Akbulut et al. 2004; Ayrılmış 2007; Ustaömer 2012).

Some problems such as low bond performance and mechanical properties can be occurred when preservatives are added to composite board prior to the production. These problems are manifested as poor glue bond quality, resin curing interference, and reduced mechanical properties (Boggio 1982).

This study was performed to determine the effects of the type and concentration of some fire retardant chemicals on the physical and mechanical properties of HDF panels covered with resin-impregnated papers.

EXPERIMENTAL

Materials

Glued wood fibers (a 50:50 blend) consisting of yellow pine and beech species were provided by Kastamonu Integrated MDF plant in Gebze, Turkey. The moisture content of the fibers was determined as 10% by oven-dry weight. Borax, boric acid, ammonium polyphosphate, and alpha-x (density: 0.84 g cm-3, pH: 3.74, boiling point: 380oC) were used as fire retardant chemical agents and obtained from Ozen Chemical Company, Istanbul, Turkey. The chemicals were then added into the fibers at target contents of 3%, 6%, and 9% based on oven-dry fiber weight as powder. Urea-formaldehyde resin (55% solid content, specific gravity 1.23) at 10% adhesive level was used. 1% ammonium chloride (NH4Cl) was added to resin as a hardening. Resin-impregnated paper (70 g m-2) was used as surface coating materials.

Preparation of Experimental Materials

All studied fire retardant at 3, 6, and 9% were mixed with glued fibers. Then HDF mats were formed, cold pressed to reduce the daylight and hot pressed. The pressing condition (temperature, pressure, and time) were presented in Table 1. Produced panel surfaces were covered with resin-impregnated paper by pressing. Prepared final panels had a thickness of 6.5 mm and a density of 0.98-1.0 gcm-^{3}. These panels were then conditioned at 65±5% relative humidity and 20±2 ^{o}C temperature for 2 weeks. After acclimatizing of the panels, the test and control specimens were cut from these panels to determine some physical and mechanical properties.

Table 1. Hot Pressing Parameters for Production of HDF and Resin-İmpregnated Paper

Parameters	HDF	Resin-impregnated paper
Temperature (^{0}C)	183	183
Press (MPa)	3.5	3.7
Time (s)	24	24

A total of 39 panels, four fire-retardant treatments, three usage proportion levels, three panels per level, and untreated control group were tested (Table 2).

Table 2. Fire Retardant Contents in Panels

Number of panels	Fire retardant chemical	Fire retardant level[a] (%)		
3	Control	---	---	---
3	Borax	3	6	9
3	Boric acid	3	6	9
3	Ammonium polyphosphate	3	6	9
3	Alfa-x	3	6	9

[a]Based on oven-dry fiber weight

Water absorption, thickness, modulus of rupture, and internal bond strength of specimens were evaluated according to the EN 317 (1999), EN 310 (1999), and EN 319 (1999), respectively.

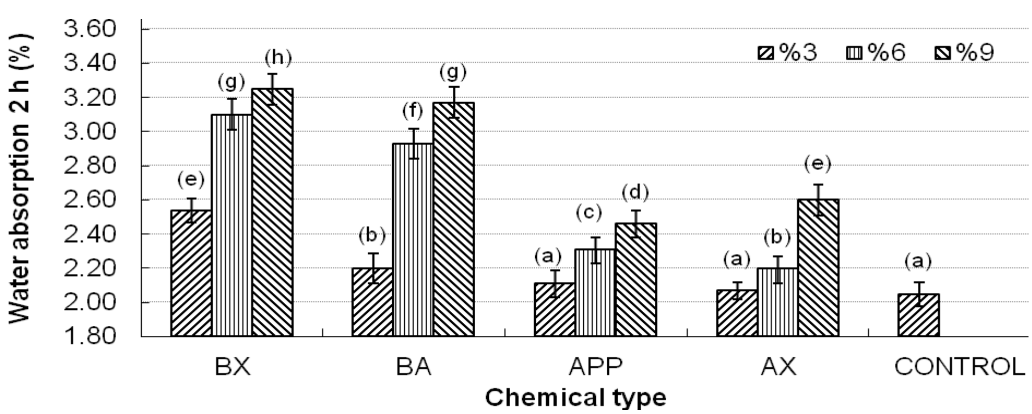
Statistical Analysis

Statistical analysis was done using SPSS statistical package program. Factors were analyzed by ANOVA and statistical significant groups were determined by DUNCAN test at a 95% confidence level.

RESULTS AND DISCUSSION

Physical Properties

The results of the water absorption of the HDF panels coated for each type of FR chemicals are presented in Fig.1. The WA values showed differences depending on types, and concentrations of fire retardant chemicals. The values of experimental panels manufactured with fire retardant chemicals were found to be higher than the WA values of control panels. The values of the WA showed a tendency to increased compared with the control as the FR chemicals increased.



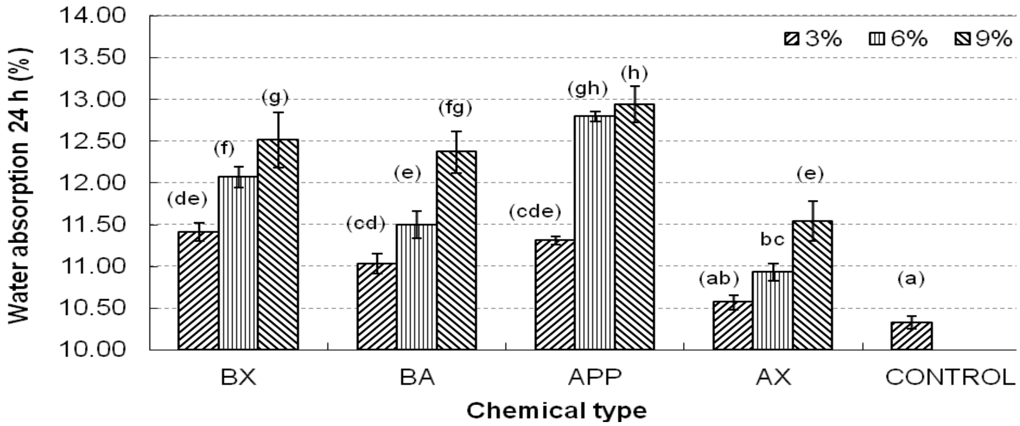


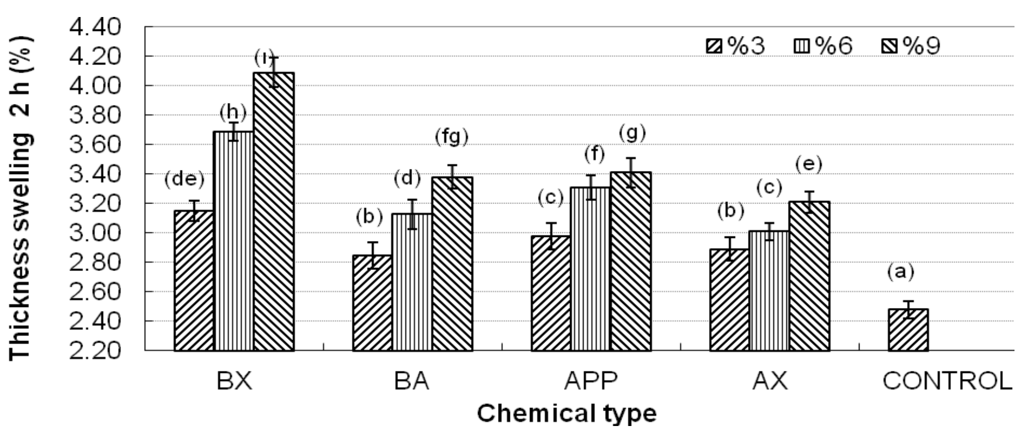
Fig.1. Average Values, Statistical Test Results for Water Absorption (2h and 24h) of the HDF Panels Coated with Resin-Impregnated Papers.

For water absorption after 2 h, and 24 h, there was a progressive increase in water absorption for all types of the FR chemicals. When comparing the WA values of the HDF panels coated, it was found the highest the values of water absorption were found with 9% concentration of borax chemical, and APP chemical for 2 h, and 24 h respectively. The WA values increased depend on increasing concentration of chemicals. The best results were obtained with 3% concentration of AX chemical for both 2 h. and 24 h.

Previous studies showed that addition of boron compounds to wood-based panels caused some decrease in physical and mechanical properties as borate content increased (Ayrılmış *et al.* 2005).

The increasing is an expected result due to structure of fire retardant chemicals. Hygroscopic nature of some boron salts may have adverse effect on dimensional stability of wood and wood-based fiberboard under humid service conditions and can cause strength losses at high retention levels. Inorganic FR chemicals can likely increase water sorption of wood (Yalınkılıç *et al.* 1995).

Furthermore, according to the statistical evaluation results, the effects of types of chemicals, concentration of chemicals, and interactions between these parameters on the water absorption of the HDF panels coated were found to be statistically significant (P<0.001).



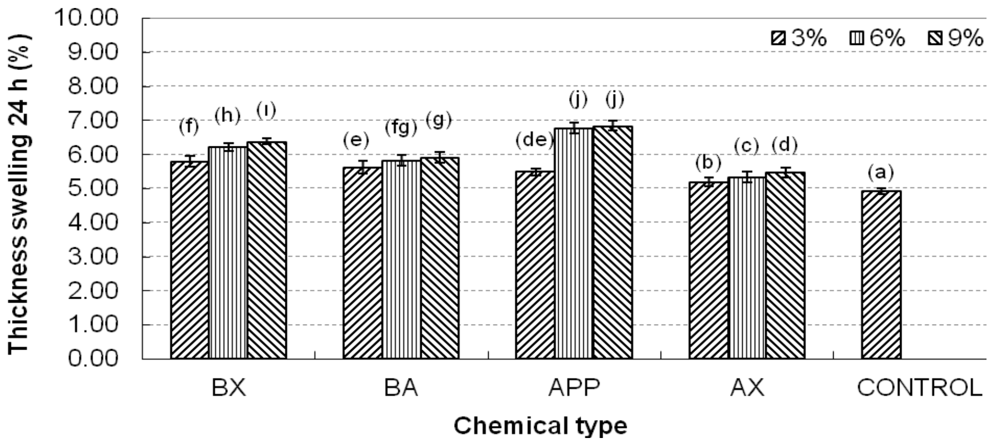


Fig.2. Average Values, Statistical Test Results for Thickness Swelling (2h and 24h) of the HDF Panels Coated with Resin-Impregnated Papers.

Fig 2 shows that the TS values of HDF panels coated had a similar trend to the WA values its. The TS values of HDF panels coated manufactured with FR chemicals were found to be higher than the TS values of control panels. When comparing the TS values of FR chemicals, it was found that the highest values were obtained with 9% concentration of BX chemical for 2 h and 9% concentration of APP chemical for 24 h. The lowest values were obtained for AX concentrations of FR chemical. It may be clearly seen that increasing concentration of FR chemicals allowed a negative effect on the TS values.

It was found that the effects of all experimental parameters on the thickness swelling of the HDF panels coated were statistically significant ($P < 0.001$).

The WA and TS values were evaluated together; it was found that the WA and TS values of HDF panels coated were higher than the values of control panels. The WA and TS values increased as the increasing concentration of chemicals. In this study, the results were revealed similar results with previous studies. It has been reported that FR chemicals have traditionally been inorganic salts, some of which are make the treated wood more hygroscopic (Denizli 1997). Therefore, FR chemicals increase moisture contents in wood products (Östman *et al.* 2001). Laks and Palardy (1990) showed that addition of zinc borate to flakeboards caused some decrease in mechanical and physical properties as borate content increased.

The results in this study were good consistent with the previous studies (Ayrılmış 2007; Ustaömer 2012). According to the results it can be said that WA and TS values of HDF panels coated decreased with increasing concentration levels of the FR chemicals.

Mechanical Properties

Fig 3 and 4 shows the results of MOR and MOE values test for HDF panels coated. The MOR values varied depending on types of chemicals and concentration of chemicals. All MOR values of the HDF panels coated produced with FR chemicals were found to be between 52.22 and 39.66 N/mm^2. The control value was found as 55.00 N/mm^2. The results indicated that the highest values of MOR strength were observed at control panels. The lowest value of MOR strength was in 9% concentration of APP chemicals.

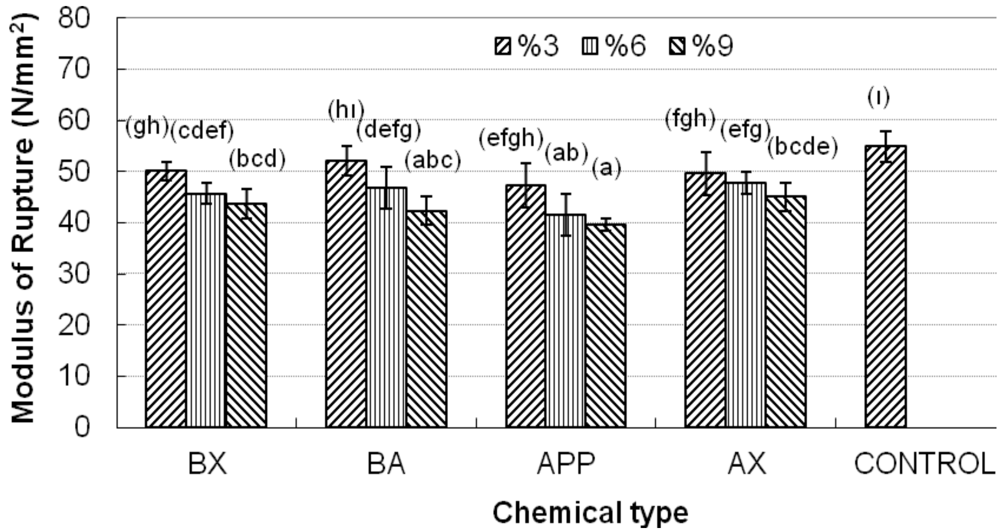


Fig.3. Average Values, Statistical Test Results for Modulus of Rupture (MOR) of the HDF Panels Coated with Resin-Impregnated Papers

The MOE values were significantly reduced, when compared to control board values. The values of panels were found to be between 3688 and 2574 N/mm^2. Control boards values were obtained as 3818 N/mm^2. The MOR and MOE values for HDF panels coated manufactured with FR chemicals were found to be lower than the MOR and MOE values of control panels. The MOR and MOE strength showed reduction compared with the controls as the FR chemicals increased. When the concentration of the FR chemicals increased, the MOR and MOE generally decreased (Hashim *et al.* 2009). This probably could be due to the presence of FR chemicals depositing on the fibers of the boards.

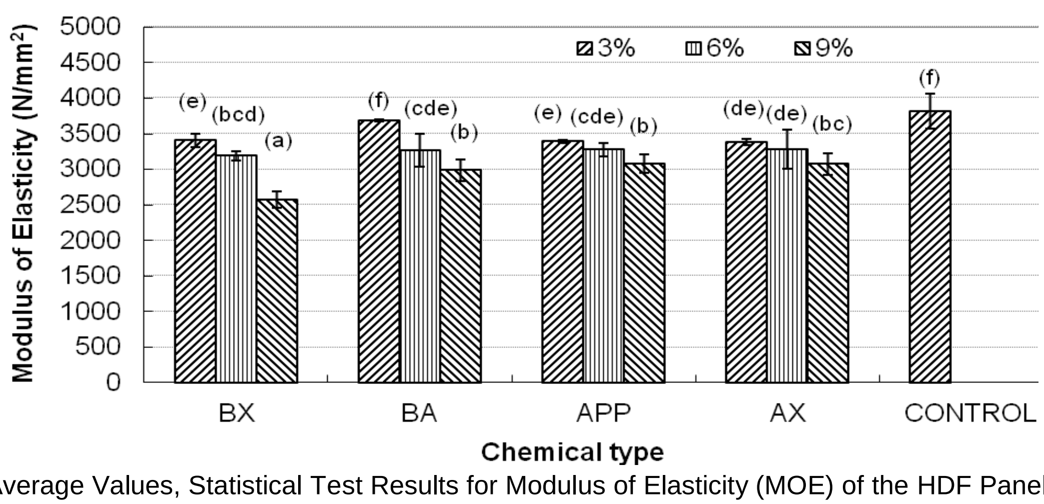


Fig.4. Average Values, Statistical Test Results for Modulus of Elasticity (MOE) of the HDF Panels Coated with Resin-Impregnated Papers

The FR chemicals are acidic or basic inorganic salts. Acids in wood could hydrolyze the branched and the longer cellulose chains. Cellulose is often thought to be primarily responsible for the strength of the wood fiber. Therefore, reducing the length of the cellulose molecules would cause a reduction in macro-strength properties (İfju 1964).

But coating of the fiberboard surfaces can improve mechanical properties of the panels (Nemli *et al.* 2005).

Fig 5 shows the results of IB test for HDF panels coated. The IB values varied depending on types, and concentration of chemicals. It was found that generally, the IB values of HDF panels coated manufactured with FR chemicals were lower than the IB values of control panels.

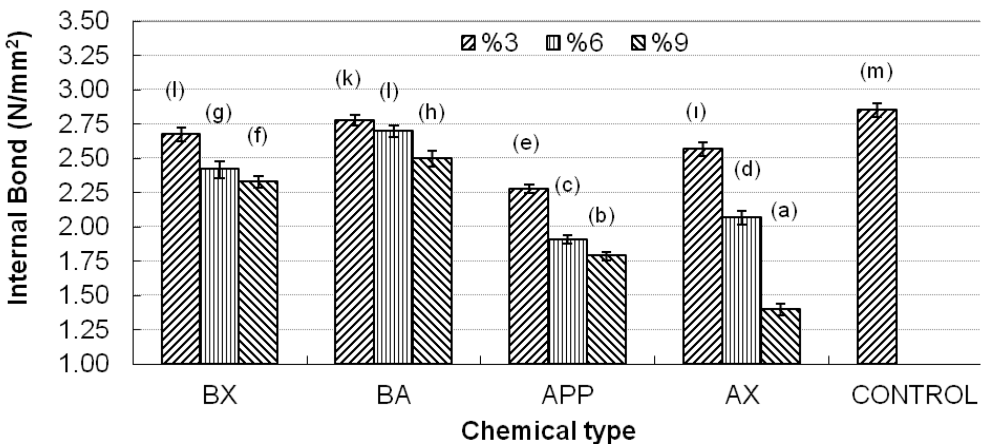


Fig.5. Average Values, Statistical Test Results for Internal Bond (IB) of the HDF Panels Coated with Resin-Impregnated Papers

The lowest values were obtained with 9% concentration of AX chemical. Increasing concentrations of FR chemicals affected negatively the IB values, and these values slightly decreased. This could be due to the same factor as that of MOR and MOE which is in a consequence of flame retardant chemicals depositing on the fibers that could interfere with the gelation of the adhesive. For boards treated with FR chemicals, the results showed an decrease in internal bond strength. When the concentration of the flame retardant chemicals increased to 9% the internal bond generally decreased.

In another study; it was determined that FR chemicals can cause some reductions in strength properties of wood. IB strength values were considerably decreased for all the FR loading levels (Ayrılmış 2007). Test results of IB were found to be compatible with previous studies. In this study, some reductions were observed in the mechanical properties.

The IB strength and bond durability losses noted in the results are probably jointly related to three issues. One is that the FR chemicals may be causing chemical and/or mechanical changes in the wood cell-wall structure and chemistry. The second is that some FR chemicals may inhibit or accelerate curing of resins by altering the requisite pH of the resin during curing. The third is that contamination of wood surface by the presence of loosely adhering crystalline deposits of FR chemicals at the glue line may interfere with the attainment of intimate fiber-to-fiber contact, which is important to maximum bond strength.

The effects of types of chemicals, concentration of chemicals, and their interaction on the internal bond strength of HDF panels coated were found to be statistically significant (P< 0.001).

CONCLUSIONS

The following conclusions were drawn from the result of the present study:

1. The WA and TS value of HDF panels coated were found to be the higher than values of control panels. The WA and TS value of experiment panels increased 9% concentration with APP chemical.
2. The TS values were found similar to trends the values of WA. The highest TS values were obtained at 9% concentration with BX chemical for 2 h. and, APP chemical for 2 h. BX and APP chemicals provided negatively affect on the physical properties.
3. The MOR and IB values were found to be the lower than values of control panels. The effect of negatively the value of MOR, MOE and IB strength obtained at 9% concentration of APP, BX, and AX chemicals, respectively.

ACKNOWLEDGMENTS

This study was supported by the Research Fund of Kahramanmaras Sutcu Imam University (Project no: 2009/3-1 D).

REFERENCES CITED

Akbulut, T., Kartal S. N. and Green, F. (2004). "Fiberboards Treated with N'-N-(1,8-Naphthalyl) Hydroxylamine (NHA-Na), Borax, and Boric Acid," *Forest Products Journal* 54(10), 59-64.

Ayrılmıs, N., Kartal, S. N., Laufenberg, T., Winandy, J. E. and White, R. H. (2005). "Physical and mechanical properties, fire, decay, and termite resistance of treated oriented strandboard," *Forest Products Journal* 55(5), 74-81.

Ayrılmış, N. (2007). "Effect of fire retardants on internal bond strength and bond durability of structural fiberboard," *Build and Environment* 42(3), 1200-1206.

Boggio, K. and Gertjejansen, R. (1982). "Influence of ACA and CCA waterborne preservatives on the properties of Aspen wafer board," *Forest Products Journal* 32(3), 22-6.

Denizli, N. (1997). "Physical and Mechanical Properties of Laminated Strand Lumber Treated with Fire Retardant," Master of Science Degree, State University of New York College of Environmental Science and Forestry, Syracuse, New York, UMI, 48130.

EN 310 (1999). "Wood-based panels: Determination of modulus of elasticity in bending and of bending strength" TSE, Ankara, Turkey.

EN 317 (1999). "Particleboards and fiberboards: Determination of swelling in thickness after immersion in water," TSE, Ankara, Turkey.

EN 319 (1999). "Particleboards and fiberboards: Determination of tensile strength perpendicular to the plane of the board," TSE, Ankara, Turkey.

Hashim, R., Murphy, R. J., Dickinson, D. J., Dinwoodle, J. M. (1994). "The mechanical properties of boards treated with vapor boron," *Forest Products Journal* 44 (10), 73-79.

Hashim, R., Sulaiman, O., Kumar, R.N., Tamyez, P.F., Murphy, R.J. and Ali, Z. (2009). "Physical and mechanical properties of flame retardant urea formaldyde medium density fiberboard," *Journal of Materials Processing Technology* 2(19), 635-640.

İfju, G. (1964). "Tensile strength behavior as a function of cellulose in wood," *Forest Product Journal* 14(8), 336-72.

Laks, P. E. and Palardy, R. D. (1990). "The development of borate-containing flakeboard," In: Proc. of the 1st Inter. Conf. on Wood Protection Diffusible Preservatives Proc. No.47355, Forest Products Society, Madison, WI pp. 76-79

Nemli, G. and Çolakoğlu, G. (2005). "Effects of mimosa bark usage on some properties of particleboard," *Turkish Journal of Agriculture and Forestry* 29, 227-230.

Östman, B., Voss, A., Hughes A., Hovde J. P. and Grexa, O. (2001). "Durability of Fire Retardant Treated Wood Products at Humid and Exterior Conditions," *Review of Literature, Fire and Materials* 25(3), 95-104.

Roger, R. M. (2005). "Handbook of wood chemistry and wood composites," p 383.

Ustaömer, D., and Usta, M. (2012). "The effects of boron compounds and different melamine contents in MUF resins on some properties of MDF panels," BioResource, (http://www.bioresources.com). 7(1), 437-446.

White, R. H., and Sweet, M. S. (1992). "Flame retardancy of wood: Present status, recent problems, and future fields," *Proceedings of 3rd Annual BCC Conference of Flame Retardancy* 250-257.

Yalınkılıc, M.K., Baysal E. and Demirci Z. (1995). "Effect of boron preservatives on hygroscopicity of brutia pine wood," *Turkey Eng Sci J.* 1(2–3), 161–168.

Article Submitted: May 17, 2013; Peer review completed: November 17, 2013; Revised version received and accepted: December 7, 2013; Published: December 15, 2013.