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# THE EFFECT OF BORON COMPOUNDS IMPREGNATION ON PHYSICAL AND MECHANICAL PROPERTIES OF WOOD POLYMER COMPOSITES

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## ABSTRACT

Wood polymer composites were prepared by styrene (ST) and different boron compounds impregnated sapwood of Oriental beech (*Fagus orientalis* L.) Boric acid (BA), borax (BX) and their mixture (1:1; w/w) aqueous solutions at 0.25, 1.00, and 4.70 % concentrations were prepared and then impregnated into wood prior to styrene treatment. The effects of borates pretreatments on the physical and mechanical properties of composites were evaluated.

Results showed that styrene considerably improved physical properties of wood such as enhanced color, oven dry density and reduced water absorption (WA) level of wood. The polymerization of styrene and the presence of polystyrene in the wood structure were confirmed by FTIR spectroscopy. It can be seen that the WA values of wood samples with boron pre-impregnated WPCs were increased slightly when compared with only styrene treated wood samples, but still they have lower values than that of the untreated wood. It was also found that the styrene treated wood samples showed better mechanical properties such as higher modulus of rupture (MOR) and compression strength parallel to grain (CSPG). The MOR and CSPG levels of WPCs pre-impregnated with borates were decreased to some extent, but still they exhibit higher the MOR and CSPG values when compared with the untreated wood.

KEYWORDS: Wood polymer composites, borates, wood, physical properties, mechanical properties.

## INTRODUCTION

Wood has been preferred for residential construction since ancient times because of its natural beauty and excellent properties, such as high specific strength, heat insulation, and ease of handling and processing (Su 1997). But wood is much more easily degraded by environmental agents, including fire, biological organisms, water, and light, than many man-made materials (Kiguchi and Evans 1998). Therefore, in recent years, there has been a rapid increase in the application of chemicals to wood materials in order to improve their physical, mechanical, biological, and fire properties (Wen-Yu 1997, Yalinkilic et al. 1999a, Brelid et al. 2000, Chao and Lee 2003). In wood polymer composites (WPCs), vinyl type monomers are polymerized into the solid polymer by means of a free radical mechanism, (Meyer 1977). In general, vinyl monomers simply bulk the wood structure by filling the capillaries, vessels and other void spaces in the wood structure (Meyer 1981). By adding bulk vinyl monomers to the void spaces in wood; compression strength, hardness, and abrasion resistance greatly improved as well as dimensional stability. Since most vinyl monomers are non-polar, there is or no interaction with the hydroxyl groups attached to the cellulose molecule. Wood polymer composites are initially used for decking and non-structural building applications, but now they have been extensively developed for a wide range of applications, including buildings and constructions, automotive, gardening and outdoor products (Li et al. 2014). Some examples of vinyl monomers are styrene, chlorostyrene, vinyl chloride, vinyl acetate, acrylonitrite, ethylene oxide, many of the acrylates, especially methylmethacrylate (Meyer 1984).

Borates have several advantages as wood preservative. In addition to imparting flame retardancy, they provide sufficient protection against wood destroying organisms, have a low mammalian toxicity and low volatility. Moreover, they are colorless and odorless (Murphy 1990, Drysdale 1994, Hafizoglu et al. 1994, Chen et al. 1997, Yalinkilic et al. 1999a). However, they are generally leachable from treated wood in ground contact under rainfall (FAO 1986, Yalinkilic et al. 1995a, b). Therefore, the utilization of boron compounds is restricted for indoor conditions. The future applications of boron preservatives depend on enhancement of their stability in wood for a reasonable period of protection (Nicholas et al. 1990) as well as the improvement of some adverse properties of boron treated wood by supplemental treatments (Yalinkilic et al. 1996). For these reasons, combinations of borates with other preservatives have been extensively evaluated for wood preservation in exterior applications (Lloyd et al. 1990, Murphy et al. 1995, Peylo and Willeitner 1995, Pizzi and Backer 1996). It is well known that vinyl monomers contribute to dimensional stability and strength properties of wood and they are expected to provide a delayed leaching of boron from wood. Boron is considered to enhance the biological and fire resistance of vinyl polymerized wood in a combination treatment system (Lutomski 1975). Fruno (1992) and Fruno et al. (1993) investigated the application of boron compounds such as boric acid, borax, boron trioxide, ammonium borate, and potassium borate to produce insoluble organic substances in wood by reacting with water glass acid treatment. As a result, it was recognized that the utilization of the water glass–boron compound system made wood into a composite material feasible of having dimensional stability with less hygroscopicity as well as having fire resistance. Baysal et al. (2007) investigated that physical, biological, mechanical, and fire properties of wood polymer composite (WPC) was obtained by vinyl monomers such as styrene (ST), methylmethacrylate (MMA), and their mixture (50:50; volume: volume) of treated sapwood of Scots pine (*Pinus sylvestris* L.). A Boric acid (BA) and borax (BX) mixture was impregnated into wood at 1 % concentration prior to monomer treatment. They found that vinyl monomers considerably improved physical properties of wood such as increased antiswelling efficiency (ASE), specific gravity (SG), and reduced water absorption (WA) levels of wood. Modulus of elasticity (MOE) and modulus of rupture (MOR) were also higher than that of untreated control specimens. Although, ASE, MOE, and MOR levels of WPC pre-impregnated with BA and BX mixture were reduced to some extent, it enhanced the fire resistance of wood. Yalinkilic (2000) investigated water absorption levels of wood polymer composites pre-impregnated with 1 % aqueous solution of boric acid. He reported that styrene was the most effective monomer followed by methyl methacrylate and mixture treatment in reducing water absorption wood.

The present study deals with some physical properties such as WA, oven dry density, color characteristics, and mechanical properties including MOR and CSPG of wood polymer composites (WPCs) pre-impregnated with aqueous solutions of boric acid and borax and theirs mixtures.

## MATERIAL AND METHODS

### Preparation of test specimens and chemicals

Wood specimens were prepared from sound wood of Oriental beech (*Fagus orientalis* L.) which met the requirements of ASTM D 1413-76 standard (ASTM D 1413-76, 1976). Boric acid (BA) and borax (BX) and their mixture (1:1; weight/weight) were used as the boron compounds. Styrene was used as vinyl monomer and was purified by alkali washing with 0.4 % NaOH aqueous solution and then washed with water for several times. The styrene monomer was removed from the aqueous phase by separatory funnel and dried with calcium chloride desiccant. Divinylbenzene (DVB) was used as the crosslinker and it was purified with 0.4 % NaOH aqueous solution to remove the inhibitor. After the alkali treatment the DVB was washed with water and dried. Benzoyl peroxide was used as an initiator for the styrene thermal polymerization and it was used as received.

### Impregnation and polymerization method

Specimens were impregnated with borates and styrene according to the ASTM D 1413-76 (ASTM D 1413-76 1976). Boric acid (BA) and borax (BX) and their mixture (1:1; weight/weight) were impregnated into wood as 0.25, 1.00, 4.70 % aqueous solutions. Following impregnation, wood specimens were dried under ambient conditions for three weeks before styrene treatment. Styrene was purified of inhibiting agents through a cleaning procedure with 15 % sodium hydroxide (NaOH), and dry calcium chloride ($CaCl_2$) granules benzoyl peroxide was subsequently added as a catalyzer. Prior to introducing a monomer solution containing both the initiator and divinyl benzene as a crosslinker, wood specimens were evacuated for 30 min at 760 mm $Hg^{-1}$ to accelerate absorption. The soaking period was 30 min. Impregnated wood specimens were then wrapped in aluminum foil before in situ polymerization process in an oven at 90°C for 4 h as described earlier (Yalinkilic et al. 1997). The Fourier Transform Infrared Spectroscopy (FTIR) was used to determine the complete impregnation and polymerization of styrene. Chemical compositions of wood samples and the polystyrene treated wood samples were identified by the FTIR Spectroscopy. Retention of boron was calculated from the following equation:

$$\text{Boron retention} = \frac{\text{GxC}}{\text{V}} \text{x } 10 \qquad (\text{kg.m}^{-3}) \qquad (1)$$

where: G - the amount of solution absorbed by wood that is calculated by $T_2$ - $T_1$;
$T_2$ - weight of wood after impregnation,
$T_1$ - weight of wood before impregnation,
C I - solution concentration as percentage,
V - the volume of the specimen as $cm^3$.

Weight percent gain (WPG) (%, w/w) due to styrene load was calculated from the following equation:

$$\text{WPG} = \frac{W_{(of)} - W_{(oi)}}{W_{(oi)}} \text{x } 100 \qquad (\%) \qquad (2)$$

where: $W_{oi}$ - the oven-dried weight (g) of a wood specimen before impregnation
$W_{of}$ - $W_{of}$ - the final oven-dried weight (g) of a wood specimen after impregnation.

## Water absorption

Wood specimens measuring 20 (tangential) x 20(radial) x 20 (longitudinal) mm were prepared from sound sapwood of Oriental beech (*Fagus orientalis* L.). In the applied method, specimens were submerged in distilled water for 24, 48, and 72 h after being evacuated for 90 min at 760 mm $Hg^{-1}$. Water absorption levels (WA) were calculated by following equation:

$$\text{WA} = \frac{W_2 - W_1}{W_2} \text{x } 100 \qquad (\%) \qquad (3)$$

where: $W_2$ - the wet weight of a wood specimen after saturation with water,
$W_1$ - the weight of a wood specimen before saturation.

## Color measurement and artificial weathering

Specimens measuring 6 x 75 x 150 mm (radial by tangential by longitudinal) were machined from the air-dried sapwood of Oriental-beech (*Fagus orientalis* L.) lumber. All specimens were conditioned at 20°C and 65 % relative humidity for two weeks before tests.

The color parameters *a**, *b**, and *L** were determined by the CIELAB method. The *L** axis represents the lightness, whereas *a** and *b** are the chromaticity coordinates. The + *a** and -*a** parameters represent red and green, respectively. The + *b** parameter represents yellow, whereas -*b** represents blue. *L** can vary from 100 (white) to zero (black) (Zhang 2003). The colors of the specimens were measured by a colorimeter (X-Rite SP Series Spectrophotometer) before and after the heat treatments. The measuring spot was adjusted to be equal or not more than one-third of the distance from the center of this area to the receptor field stops. The color difference, (*ΔE**) was determined for each wood as follows (ASTM D 1536–58 1964):

$$\Delta a^* = a_f^* - a_i^* \qquad (4)$$

$$\Delta b^* = b_f^* - b_i^* \qquad (5)$$

$$\Delta L^{*} = L_{f}^{*} - L_{i}^{*} \tag{6}$$

$$(\Delta E^{*}) = [(\Delta a^{*})2 + (\Delta b^{*})2 + (\Delta L^{*})\ 2]\ ½ \tag{7}$$

where: Δa*, Δb*, and ΔL* - the changes between the initial and final interval values.

Color measurements were made in the direction parallel to the fiber. Artificial weathering experiment was performed in a QUV weathering device (Q - Lab, USA) equipped with eight UVA 340 lamps according to principles of ASTM G154 (2006) standard. Specimens were exposed to cycles of 8 h UV-light irradiation followed by condensation for 4 h in QUV device for a total of 500 h. The average irradiance was 0.89 $W.m^{-2}$ at the maximum intensity of 340 nm wavelengths ($\lambda_{max}$ = 340 nm). The temperature at the light irradiation period and at the condensation period was 60 and 50°C, respectively.

## Oven dry density

Wood specimens 20 (tangential) x 20 (radial) x 20 (longitudinal) mm were prepared from air-dried sapwood of Oriental beech for oven dry density. Oven dry density values of wood specimens were determined according to TS 2472 standard (1976) and the values were calculated with the following equation:

$$d_0 = \frac{W_{(0)}}{V_{(0)}} \qquad (g.cm^{-3}) \tag{8}$$

where: $d_o$: - oven dry density value of wood specimens,
$W_o$ - oven dry weight of wood specimens,
$V_0$ - oven dry volume of wood specimens.

## Modulus of rupture

The modulus of rupture (MOR) of wood specimens was determined according to TS 2474 standard (1976). Wood specimens had been conditioned at 20°C and 60 % RH for 6 weeks prior to testing. The MOR of wood specimen was calculated using the following formula;

$$\mathrm{MOR} = \frac{3 \times P \times I}{2 \times b \times h^2} \qquad (kg.cm^{-2}) \tag{9}$$

where: P - the maximum load (kg),
I - the span (cm),
b - the width of the specimen (cm),
h - the thickness of the specimen (cm).

## Compression strength parallel to grain

The compression strength parallel to grain (CSPG) test was performed according to the TS 2595 (1977) standard by using a universal test machine, and applying 6 $mm.min^{-1}$ loading rate. Wood specimens had been conditioned at 20°C and 60 % RH for 6 weeks prior to testing.

## Evaluations of test results

Physical and mechanical 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.

# RESULTS AND DISCUSSION

Chemical compositions of untreated wood samples and the styrene treated wood samples were identified by the Fourier Transform Infrared Spectroscopy (FTIR). Fig. 1a shows the FTIR spectrum of the cellulose with typical bands for cellulose at 3345 $cm^{-1}$ (hydroxyl groups), 2900 $cm^{-1}$ (C-H stretchings) and 1050 $cm^{-1}$ (ether groups C-O-C stretchings). After the polymerization of styrene, as evident from FTIR spectrum, Fig. 1b indicates the presence of polystyrene and the cellulose functional groups at the same wood sample. The peak at 3330 $cm^{-1}$ corresponds to the hydroxyl groups of cellulose and the absorption at 3025 $cm^{-1}$ corresponds to C–H stretching of the aromatic ring coming from polystyrene. The bands at 2921 $cm^{-1}$ (C-H stretchings) and 1026 $cm^{-1}$ (ether groups C-O-C stretchings) show the cellulose part. The peaks at 1599, 1492, and 1449 $cm^{-1}$ are the phenyl ring coming from polystyrene. Out-of plane ring C=C bending can be seen at 697 $cm^{-1}$.

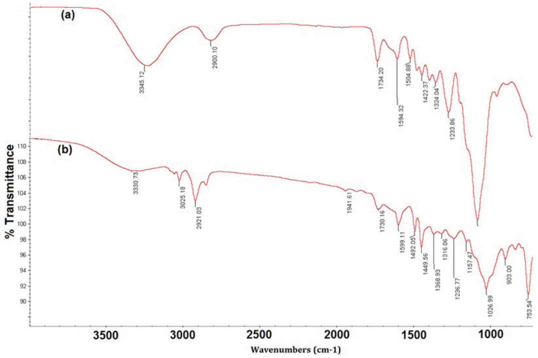

*Fig. 1: FTIR spectrum of untreated wood a), FTIR spectrum of wood PS composite b).*

The FTIR spectrum of polystyrene (PS) impregnated wood samples confirms the chemical structure of both PS and cellulose and shows that the impregnation of PS on wood was done by successfully. It can be seen that there is no unreacted monomer (styrene) and all of them were polymerized by heat process.

## Water absorption levels

Tab. 1 shows WA, boron retention ($kg.m^{-3}$), and WPG (%) levels of WPCs pre-impregnated with borates. Boron retention was calculated as 1.37 to 29.35 $kg.m^{-3}$. Also, weight percent gain (WPG) due to styrene load was found as 71.38 to 92.57 %. Our results showed that pre-impregnation of borates reduced polymer loading of wood specimens. Results indicated that the water absorption rate of the wood samples for the first period was higher than that of the other periods, which is consistent with the previous studies (Alma 1991, Hafizoglu et al. 1994, Yildiz 1994). These results may be due to WA into available empty pores in wood at the beginning of soaking and the reduction of those wood spaces over time (Yalinkilic et al. 1995c). It is easily observed that styrene treatments significantly decreased the WA. Moreover, decrease of WA is mainly caused by the water repellency and swelling effect of the styrene. Reduction of WA is due to increase by hydrophobicity (Meyer 1984). Because styrene is non polar, it hardly reacts with hydroxyl groups of cellulose molecules in wood (Yalinkilic 2000). It was also found that WA of wood specimens pre-impregnated with borates was higher than that of the only styrene impregnated wood. Because, high WA of boron-styrene impregnated wood might have been caused by low monomer diffusion into the fine structure of cell wall due to deposited boron crystals (Yalinkilic 2000). Baysal et al. (2006) investigated that WA level of WPCs pre-impregnated with a mixture of BA and BX (7:3; weight/weight). They found that WA of WPCs pre-impregnated with a mixture of BA and BX was higher than only styrene impregnated wood. Our results are in good agreement with the data of Baysal et al. (2006).

*Tab. 1: WA of WPCs pre-impregnated with borates.*

| **Chemicals** | **Concentration (%)** | **Boron retention (kg.m$^{-3}$)** | **WPG (%)** | **WA (%)** | | |
|---|---|---|---|---|---|---|
| | | | | **24 h** | **48 h** | **72 h** |
| | | | | **Mean ± SD** | **Mean ± SD** | **Mean ± SD** |
| Control | - | - | - | 62.79 ±5.43 a | 70.48 ±3.57a | 76.32 ±6.39a |
| ST | - | - | 92.57 | 17.14 ± 3.01 f | 23.15 ±3.47 g | 27.44 ±3.24 d |
| (BA+ ST) | (0.25) | 1.60 | 88.86 | 22.94 ±3.46d | 29.49 ±4.26 d | 38.53 ±4.84b |
| | (1.00) | 5.52 | 80.62 | 20.94 ±1.38 e | 28.03 ±3.59e | 32.3 ±2.40 c |
| | (4.70) | 27.78 | 76.48 | 28.90 ±3.49b | 33.33 ±4.28b | 39.58 ±3.12 b |
| (BX+ST) | (0.25) | 1.55 | 85.84 | 19.67 ±2.65def | 23.94 ±2.64fg | 30.43 ±3.89 d |
| | (1.00) | 6.16 | 83.97 | 21.49 ±2.82 d | 24.79 ±2.6ef | 32.79 ±3.51c |
| | (4.70) | 29.35 | 80.78 | 25.96 ±3.90 c | 29.96 ±4.56 c | 39.96 ±4.30b |
| (BA+BX)+ST | (0.25) | 1.37 | 85.96 | 18.03 ±2.67f | 26.81 ±3.53f | 32.18 ±3.85 c |
| | (1.00) | 4.90 | 77.51 | 20.05 ±1.80 f | 26.08 ±2.05g | 36.51 ±4.97b |
| | (4.70) | 28.15 | 71.38 | 22.94 ±3.85 d | 27.96 ±3.94de | 36.85 ±3.71b |

Ten replicates were made for each treatment group. Small letters given as superscript over WA values represent HG obtained by statistical analysis with similar letters reflecting statistical significance at the 95 % confidence level. SD: Standard deviation, ST: Styrene, BA: Boric acid, BX: Borax.

## Color changes

The changes of *ΔL**, *Δa**, *Δb**, and *ΔE** after artificial weathering of WPCs pre-impregnated with borates are given in Tab. 2.

*Tab. 2: Color changes of WPCs pre-impregnated with borates after artificial weathering.*

| **Chemicals** | **Conc. (%)** | **Before artificial weathering** | | | **After 500 h artificial weathering** | | | **After 500 h artificial weathering** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | - | **Li*** | **ai*** | **bi*** | **Lf*** | **af*** | **b*f** | **ΔL*** | **Δa*** | **Δb*** | **ΔE*** |
| Control | - | 67.18 | 10.82 | 19.67 | 54.59 | 16.73 | 31.65 | -12.59 | 5.91 | 11.99 | 18.36 |
| ST | - | 55.07 | 13.14 | 20.84 | 52.56 | 17.44 | 33.59 | -2.51 | 4.30 | 12.74 | 13.68 |
| (BA + ST) | 0.25 | 45.15 | 7.84 | 16.57 | 39.26 | 11.28 | 20.14 | -5.89 | 3.45 | 3.57 | 7.70 |
| | 1.00 | 50.92 | 13.92 | 21.74 | 50.69 | 14.16 | 26.54 | -0.23 | 0.24 | 4.81 | 4.82 |
| | 4.70 | 48.66 | 14.10 | 20.35 | 45.17 | 17.35 | 25.98 | -3.49 | 3.26 | 5.64 | 7.38 |
| (BX + ST) | 0.25 | 46.99 | 10.96 | 16.43 | 46.56 | 15.08 | 27.42 | -0.43 | 4.13 | 10.99 | 11.74 |
| | 1.00 | 45.63 | 10.40 | 17.93 | 43.20 | 15.23 | 26.54 | -2.44 | 4.83 | 8.62 | 10.17 |
| | 4.70 | 48.85 | 10.87 | 15.35 | 47.40 | 12.64 | 26.05 | -1.46 | 1.77 | 10.71 | 10.95 |
| (BA + BX) + ST | 0.25 | 50.46 | 11.73 | 19.80 | 49.18 | 12.72 | 27.03 | -1.29 | 0.98 | 7.23 | 7.41 |
| | 1.00 | 50.56 | 14.04 | 21.51 | 50.00 | 16.22 | 30.73 | -0.56 | 2.19 | 9.22 | 9.49 |
| | 4.70 | 43.40 | 14.67 | 19.79 | 39.74 | 17.53 | 24.30 | -3.66 | 2.85 | 4.51 | 6.47 |

Five replicates were made for each treatment group. BA: Boric acid, BX: Borax, ST: Styrene,
Conc.: Concentration

The decrease in *L** indicates that the specimens become darker after artificial weathering. The darkening of WPCs might be due the to degradation of lignin and other noncellulosic polysaccharides (Hon and Chang 1985, Grelier et al. 2000, Petric et al. 2004). *ΔL** of control specimen was higher than WPCs after artificial weathering. While *ΔL** of control was (-12.59), it changed from (–0.23) to (-5.89) for WPCs after artificial weathering. While the positive values of a* indicate a tendency of wood surface to become reddish, positive values of *b** indicate a tendency of wood surface to yellowing. While *Δa** of control was (5.91), it changed from (0.24) to (4.83) for WPCs after artificial weathering. Our results showed that *Δa** of control specimen gave higher values than that of WPCs. Positive values of *Δb** indicate a tendency of wood surface to yellowing. This increase may be explained by the modification of some chromophoric groups of lignin (Grelier et al. 2000). According to our results, *Δb** of styrene impregnated WPC was higher than that of control specimen after artificial weathering. Also, borate impregnation caused a decrease in *Δb** of WPCs after artificial weathering.

## Oven dry density

The oven dry density values of WPCs pre-impregnated with borates are given in Tab. 3. The oven dry density increased sharply from 0.644 to 0.866 g.cm$^{-3}$ after the wood was impregnated with styrene. The increase in density due to the amount of monomer absorbed by wood (Chao and Lee 2003). These results show that while the highest oven dry density value of WPC was obtained with styrene (0.866 g.cm$^{-3}$), the lowest oven dry density value (0.644 g.cm$^{-3}$) was observed with the control specimen. There is a statistical difference in oven dry density values between control and WPCs.

*Tab. 3: Oven dry density values of WPCs pre-impregnated with borates.*

| **Chemicals** | **Concentration (%)** | **Oven dry density (g.cm$^{-3}$)** |
|---|---|---|
| | | **Mean ± SD** |
| Control (Untreated) | - | 0.644 ± 0.016$^{a}$ |
| ST | - | 0.866 ± 0.064$^{b}$ |
| (BA+ ST) | (0.25) | 0.840 ± 0.040$^{b}$ |
| | (1.00) | 0.847 ± 0.050$^{b}$ |
| | (4.70) | 0.855 ± 0.027$^{b}$ |
| (BX+ST) | (0.25) | 0.844 ± 0.027$^{b}$ |
| | (1.00) | 0.827 ± 0.057$^{b}$ |
| | (4.70) | 0.837 ± 0.040$^{b}$ |
| (BA+BX)+ST | (0.25) | 0.825 ± 0.071$^{b}$ |
| | (1.00) | 0.820 ± 0.069$^{b}$ |
| | (4.70) | 0.835 ± 0.074$^{b}$ |

Ten replicates were made for each treatment group. Small letters given as superscript over oven dry density values represent HG obtained by statistical analysis with similar letters reflecting statistical significance at the 95 % confidence level. SD: Standard deviation,

ST: Styrene, BA: Boric acid, BX: Borax

Our results showed that borate pre-impregnation caused a decrease in oven dry density values of WPCs. But, it is not of statistical importance. Density plays an important role in influencing both physical and mechanical properties of wood and wood-based materials (Akbulut et al. 2004). There is, in reality, a close correlation between mechanical properties, hardness, abrasion resistance, and heat value of wood, and density (Kollman and Cote 1968). Also, wood density is an important factor determining possible uses of wood. For instance, strength, flexibility and surface hardness of heavy wood are more than those of light wood. It gives better protection against corrosive effects. In some cases, it is desirable for wood to be soft, for easy processing, lower shrinkage and swelling. This can be possible when wood is light (Ors and Keskin 2008). Baysal et al. (2007) investigated density values of WPCs pre-impregnated with a mixture of BA and BX. They found that the specific gravity of wood specimens pre-impregnated with a mixture of BA and BX was lower than only styrene impregnated wood. The results of this study are consistent with these findings.

## Modulus of rupture

Modulus of ruptures of WPCs pre-impregnated with borates are given in Tab. 4.

*Tab. 4: MOR of WPCs pre-impregnated with borates.*

| **Chemicals** | **Concentration (%)** | **(MOR) kg.cm$^{-2}$** |
|---|---|---|
| | | **Mean ± SD** |
| Control (Untreated) | - | 1051 ± 89$^{c}$ |
| ST | - | 1359 ± 82$^{a}$ |
| (BA+ ST) | (0.25) | 1283 ± 58$^{ab}$ |
| | (1.00) | 1260 ± 104$^{ab}$ |
| | (4.70) | 1246 ± 127$^{ab}$ |
| (BX+ST) | (0.25) | 1285 ± 115$^{ab}$ |
| | (1.00) | 1262 ± 106$^{ab}$ |
| | (4.70) | 1254 ± 182$^{ab}$ |
| (BA+BX)+ST | (0.25) | 1314 ± 144$^{ab}$ |
| | (1.00) | 1278 ± 186$^{ab}$ |
| | (4.70) | 1249 ± 112$^{ab}$ |

Ten replicates were made for each treatment group. Small letters given as superscript over MOR values represent HG obtained by statistical analysis with similar letters reflecting statistical significance at the 95 % confidence level. SD: Standard deviation, ST: Styrene,

BA: Boric acid, BX: Borax

While the highest MOR (1359 kg.cm$^{-2}$) was obtained from wood impregnated with styrene, the lowest MOR (1051 kg.cm$^{-2}$) was observed in the control specimen. There is a great difference in MOR levels between the control and WPCs. But, there is not a statistical difference in MOR levels among all WPCs. It was found that wood specimens impregnated only with styrene generated a higher MOR level (1359 kg.cm$^{-2}$) compare to that of borates pre-impregnated of WPCs (1246- 1314 kg.cm$^{-2}$). It can be said borate pretreatment increased the rate of hydrolysis in the wood, thereby causing a loss in strength (Kollmann and Cote 1968). Yalinkilic et al. (1999b) reported that wood with WPC treatment, on the other hand, improved MOR of wood. The styrene and methylmethacrylate mixture was the most effective monomer followed by ST and MMA in increasing MOR of wood. Baysal et al. (2007) found that MOR of WPCs pre-impregnated with borates was reduced in some extent. According to our results, MOR of WPCs pre-impregnated with borates was reduced in some extent. But, it is not of statistical importance. Our results showed that higher concentration levels of borates resulted in lower MOR of WPCs.

### Compression strengths parallel to grain

The CSPG values of WPCs pre-impregnated with borates are given in Tab. 5. Wood samples on treatment with styrene showed an improvement in CSPG. Untreated wood samples show less compression because of the buckling of the relatively thin cell wall. In treated wood, polymer in the cell lumen might help to restrain the cell wall from buckling under compression (Devi and Maji 2007). Devi and Maji (2007) reported that wood samples on treatment with polymers (either styrene or styrene/GMA) showed an improvement in compression strength when tested in both parallel and perpendicular to fiber direction.

*Tab. 5: CSPG of WPCs pre-impregnated with borates.*

| Chemicals | Concentration (%) | CSPG ($kg.cm^{-2}$) |
|---|---|---|
| | | Mean ± SD |
| Control (Untreated) | - | $747 \pm 56^{d}$ |
| ST | - | $887 \pm 52^{a}$ |
| (BA+ ST) | 0.25 | $843 \pm 28^{bc}$ |
| | 1.00 | $832 + 25^{bc}$ |
| | 4.70 | $814 \pm 12^{c}$ |
| (BX+ST) | 0.25 | $860 \pm 50^{b}$ |
| | 1.00 | $844 \pm 36^{bc}$ |
| | 4.70 | $822 \pm 45^{c}$ |
| (BA+BX)+ST | 0.25 | $838 \pm 37^{bc}$ |
| | 1.00 | $847 \pm 32^{bc}$ |
| | 4.70 | $830 \pm 41^{bc}$ |

Ten replicates were made for each treatment group. Small letters given as superscript over CSPG values represent HG obtained by statistical analysis with similar letters reflecting statistical significance at the 95 % confidence level. SD: Standard deviation, ST: Styrene,
BA: Boric acid, BX: Borax.

Our results showed that wood specimens only styrene impregnated generated higher CSPG level (887 $kg.cm^{-2}$) compare to that of borates pre-impregnated of WPCs (814-860 $kg.cm^{-2}$). Water-borne preservative treatments generally reduce the mechanical properties of wood. Because water borne preservative chemicals physically react with the wood cell wall material (Fruno and Gato 1978). Toker et al. (2008) and Simsek et al. (2010) reported that compression strength parallel to grain values of wood specimens treated with borates were lower compared to untreated control specimen. Our results are consistent with the findings of the aforementioned studies. According to our results, there is a statistical difference in CSPG levels between control and WPCs. Also, there is a statistical difference between styrene only impregnated wood specimens and borates pre-impregnated of WPCs.

## CONCLUSIONS

In this study, some physical and mechanical properties of styrene-treated and boron compounds pre-impregnated WPCs were investigated. The results show that the boron impregnation before the styrene treatment of WPCs resulted in generally an improvement of the color characteristics after artificial weathering, but the reduction of modulus of rupture, compressive strength and oven dry density of the composites to some extent. The styrene treatment of wood decreased the water absorption (WA) because of the hydrophobic character of the polystyrene. However, the boron impregnation of the WPCs resulted in a higher WA values as expected adverse effect.

As a conclusion, as well as their good mechanical and physical properties, wood polymer composites are the materials having the low combustion properties. Boron compounds are recognized as biologically active, flame retardant and, environmentally safe chemicals (Williams 1990, Lloyd 1993, Laks and Manning 1994). Threshold levels of boron against microorganisms and insects were extensively studied by many researchers (Tamashiro et al. 1991, Grace et al. 1992, Lloyd 1993, Drysdale 1994). Very low loading of boron (0.10- 0.50 %) was generally effective against fungi while more loading over 1 % is necessary for insecticidal activity. As for fire retardancy, high boron should be given to wood for a required protection level (LeVan and Tran 1990). For this reason, in this study, loading of borate solutions were used at 0.25 and 1.00 % rates to protect wood from fungi decay, insect attacks, and 4.70 % rate borate was used as fire retardancy. Thus, a dual treatment in which borate impregnation is followed by styrene treatment may be of advantage in fire and biological properties as well as dimensional stability and strength properties.

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