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ORIGINAL ARTICLE

Physical properties of Oriental beech impregnated and coated with some chemicals

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Abstract

In this research, oven-dry density, air-dry density, and water absorption levels of Oriental beech treated with flame-resistant chemicals (FRC) and coated with polyurethane/polyure (PU) and epoxy (EP) were evaluated. According to ISO 3129 standard, the experimental specimens were made from Oriental beech wood. Wood specimens were subjected to 3% aqueous solutions of boric acid, borax, a boric acid and borax mixture (1:1; weight: weight), ammonium sulphate, and polyurethane/polyurethane, and epoxy resins before being coated with these substances. Results showed that oven-dry and air-density values of PU coated wood were much higher than EP coated wood. Water absorption (WA) levels of PU coated of wood were lower than EP coated wood. While FRC treated and PU coated wood resulted in lower WA levels than only PU coated wood, FRC treated and EP coated wood resulted in higher WA levels than only EP coated wood.

Keywords: *coating, epoxy resin, impregnation, polyurethane/polyure resin, physical properties.*

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1. Introduction

Wood material has some important properties compared to other engineering materials. For example; wood materials have superior properties such as aesthetically superior to different materials, can be easily processed and shaped, can be combined with simple tools, low cost, environmentally friendly, abundant in nature, carbon-retaining and renewable material[1]. In previous studies, it has been indicated that there is an important relationship between these physical properties and density. For example; as wood density increases, the hardness, flexibility, strength of wood increases and it is more resistant to abrasive effects[2].

The expansion and shrinkage of wood with the effect of moisture is called "working of the wood"[3]. For this reason, undesirable situations such as cracking, shrinkage, and expansion can occur in the wooden material. Generally, wood material is used preferentially in exterior cladding, door-window joinery and in the construction of park-garden furniture and decoration works[3]. However, wood material, which no protection measures are taken, is exposed to weathering effects in a short time. Cracks occur in the material due to continuous wetting and drying, and color and mold fungi develop on the surface, and on the other hand, the sun rays destroy the wood layer and substances that can be removed by the effect of rain and wind. Thus, the wood material gains a dirty appearance[4]. To shield wood against these effects, many different techniques are used. Impregnation, or the penetration of chemicals into wood substance, is the most significant of them. The impregnation method protects the wood material from burning, weathering, fungus and insect infestation, water absorption, etc. recommended to protect against the effects. It is known that chemicals such as pentachlorophenol, copper/chromium/arsenic (CCA), copper/chromium /boron (CCB), acid copper chromate, ammonia, copper/arsenic, which are commonly used as preservatives, are harmful to the environment[5,6]. To eliminate these chemicals, the impregnation industry is in search of new environmentally friendly chemicals. One of them is the aqueous solutions of boron compounds and they can penetrate the wood material very well. Boron compounds have gained currency because of their high resistance to biological destruction, their talents to be easily coated to the wood surface by unraveling in water, their good diffusion to wood material, their easy and cheap availability, and their significantly increasing the wood's resistance to fire[5,6].

Another method used to protect the wood material surface against the effect of moisture is to stop the contact of water with the wood surface by surface treatments (paints, varnishes, water repellents, etc.). Recently, different surface products coated with wood material have been on the market and many studies have been carried out on these products.

Wood material becomes more resistant to photochemical degradation, dimensional changes, and biological organisms after being impregnated and applied to the surface with various coatings or materials such as varnish/paint[7-9].

Similar studies have been carried out in the literature on this subject. Baysal et al.[10] investigated some physical properties, such as water uptake of paradise wood treated with various boron compounds and monomer water-repellent substances. In the study; borax, boric acid, and borax and boric acid mixture (7:3; weight: weight) were used as borates; styrene, methyl methacrylate, and a mixture of styrene+methylmethacrylate (7:3; vol:vol) and isocyanate were preferred as water repellents. In the study; vacsol, immersol WR, polyethylene glycol-400, Tanalith-CBC and phosphoric acid, which are commercial impregnation materials, were also tested for comparison purposes. According to the results, the water repellents preferred in the study provided an important decrease in the water absorption rate of the specimens, and a similar effect was achieved in the water repellents treatment coated on boron compounds.

Baysal et al. [11] examined the density of wood polymer composites pretreated with a mixture of boric acid and borax. According to their results, it was found that the density of wood polymer composites increased compared to the untreated control specimen. Studies on the physical features of wood that has been coated with various coating materials and impregnated with various chemicals have been published in the literature. There are, however, hardly any investigations on wood coated with polyurea/polyurethane and epoxy resins and impregnated with flame resistant chemicals. This work represents the first attempt in the body of literature to achieve this goal. In this study, a two-step approach was used to made new coating materials that could enhance the physical properties of the wood. Before the coating procedure, an impregnation approach utilizing FRC which are boron compounds and ammonium sulfate, was used. The wood specimens were first primed with epoxy resin using Sikafloor®-156 (EPR), and after that, Sikalastic®-851 R, a polyurethane/polyure, was applied to coat them. In this study, it was aimed to investigate some physical characteristics such as oven-dry density, air-dry density, and water absorption levels of Oriental beech treated with some flame-resistant chemicals and coated with polyurethane/polyure and epoxy (resins.

2. Materials and Methods

2.1 Preparation of test specimens

In accordance with ISO 3129 standard, specimens of wood were prepared in 20 mm × 20 mm x 20 mm (radial, tangential, and longitudinal) sizes for oven dry density, air-dry density, and water absorption tests[12]. The images of oven dry density (ODD), air-dry density (ADD), and water absorption (WA) of levels of control group are given in Figure 1. In Table 1, the sizes and numbers of all specimens prepared according to the test standards are given.

2.2 Impregnation procedure

Boric acid (BA), borax (BX), and ammonium sulfate (AS) were used as flame-resistant chemicals. Oriental beech specimens were treated with 3% aqueous solution of BA, BX, AS, and a mixture of BA and BX (1:1; weight/weight).

Boric acid is also known as orthoboric acid. It consists of 3 hydrogen, 3 oxygen and 1 boron atom. Due to its chemical properties, it can show very different effects. These properties

Table 1. Test specimens dimensions and numbers.

Specimens' dimensions	Test types	Number of specimens
20 mm × 20 mm x 20 mm	Oven dry density	110
20 mm × 20 mm x 20 mm	Air-dry density	110
20 mm × 20 mm x 20 mm	Water absorption	110

Figure 1. Image of control specimens (WA: Water absorption; ADD: Air-dry density; ODD: Oven-dry density).

are mild antiseptic, antifungal and antiviral properties. It is known as the conjugate acid of dihydrogen borate [13].

Borax's solubility is inversely correlated with the rise in water temperature. In cold water, it is only very slightly soluble, but as the temperature rises, it becomes much more soluble. Borax has a mild alkalinity and reacts with water to produce an alkaline solution. Borax is considerably dissolve in ethylene glycol, only marginally dissolve in acetone, and only moderately dissolve in diethylene glycol and methanol. Borax melts at 743 °C (anhydrous), reaching its boiling point at 1.575 °C (anhydrous). Borax density is 2.4 g / cm^3[14].

Ammonium sulphate contains 20% nitrogen and 22% sulfur in its composition. The inorganic ammonium salt of sulfuric acid is crystalline and very soluble in water. It has an acidic pH and can be broken down easily[15].

The specimens were impregnated according to ASTM D1413-07[16] standard. The retention amount of the FRC was measured by the Equation 1.

$$Retention = \frac{G.C}{V} x10^3 (Kg / m^3) \quad (1)$$

In here;

$G = T_2 - T_1$

T2 = Specimens' weight after impregnation (g)

T1 = Specimens' weight before impregnation (g)

V = Volume of specimen (cm^3)

C = Concentration of solution (%)

2.3 Coating procedure

The impregnated test specimens were coated after receiving an epoxy component primer coat (Sikafloor®-156) and a polyurethane/polyure coating (Sikalastic®-851 R). According to specimens with the PU label, the coatings were first produced with epoxy and then coated with polyurethane/polyure.With a low viscosity, solvent-free composition, compressive strength of 95 N/mm^2, flexural strength of 30 N/mm^2, and shore D hardness of 83 (seven days), Sikafloor®-156 is a two-component flooring product. A/B's mixing ratio was one-third of the volume ratio[17]. Sikafloor®-156 consists of 1-part A and 1-part B chemicals. In line with the recommendations of the company, 3 A component and 1 B component were mixed and coated with 2 layers of wood[18]. Sikalastic®-851 R is a two-component, elastic, crack-bridging, modified polyurethane/polyurea hybrid resin with rapid curing. The two components of Sikalastic®-851 R are component A, an isocyanate derivative, and component B, a polyol/amine derivative[19]. Utilizing specialized polyure coating equipment (GAMA G-30 H) with consumption rates of 1.7 kg/m^2 to 2.2 kg/m^2, 2 layers were done to the floor, with the second layer beginning no later than six hours following the first layer.

2.4 Oven-dry density test

The test specimens' oven-dry densities were calculated with the help of TS ISO 13061-2 standard[20]. This standard required that test specimens be dried at 103 °C±2 until they reached a consistent weight. Following cooling, the specimens were weighed on an analytical scale with a 0.01 g sensitivity, their dimensions were evaluated using a precision caliper with an accuracy of 0.01 mm, and their volumes were measured using the stereo metric method. Then, using Equation 2, determine the oven-dry density (δ_0), oven-dry weight (M_0), and oven-dry volume (V_0) values.

$$\delta_0 = \frac{M_0}{V_0} (g / cm^3) \quad (2)$$

In here;

M_0 = Oven-dry weight of specimen (gr)

V_0 = Oven-dry volume of specimen (cm^3)

2.5 Air-dry density test

The test specimens' air-dry density values were calculated in accordance with TS 2472[20] standard. Wood specimens were kept in the cabinet at 20°C and 65% relative humidity until they reached a consistent weight. It was then weighed using an analytical balance with a sensitivity of 0.01 g, the dimensions were measured using a caliper with a sensitivity of 0.01 mm, the volumes were calculated using the stereometric method, and the air-dry density was measured using the values of the air-dry weight (M_{12}) and volume (V_{12}) in accordance with Equation 3.

$$\delta_{12} = \frac{M_{12}}{V_{12}} (g / cm^3) \quad (3)$$

In this equation;

M_{12} = Air-dry weight of specimen (gr)

V_{12} = Air-dry volume of specimen (cm^3)

2.6 Water absorption test

Wood specimens were kept in distilled water for 1, 8, 24, 72, 120, 168, and, 336 hours under room conditions. After each soaking period, specimens were taken out of water, dried with paper and weighted. The distilled water used in this experiment is a liquid that does not reflect light and is permeable. For this reason, it is used in optical experiments and instruments. In addition, due to the heating and evaporation of the water during the distillation process, the distilled water is largely free of microorganisms. In this study, WA of the by each specimen was calculated with the Equation 4.

$$WA = \frac{Mf - Moi}{Moi} x100 \quad (4)$$

In here;

WA = Water absorption (%),

M_f = Weight of specimen after water absorption (gr),

M_{oi} = Oven dry weight of specimen after impregnation (gr).

2.7 Statistical evaluation

The results of the oven dry density, air-dry density, and water absorption tests were statistically analyzed using the SPSS program, which also applied the Duncan test and an analysis of variance with a 95% confidence level. Different letters denoted statistical significance in homogeneity groups (HG) statistical evaluations.

3. Results and Discussions

3.1 Oven-dry and air-dry density

The oven-dry density values of Oriental beech treated with FRC and coated with PU and EP are presented in Table 2.

The oven dry densities of treated with FRC and coated with PU and EP of wood specimens were changed from 0.72 g/cm^3 to 1.32 g/cm^3. According to our results, the oven dry density values of treated with FRC and coated with PU and EP of wood specimens were much higher than that of control sample. Oven-dry density increased from 0.65 g/cm^3 to 1.21 g/cm^3 after the wood was coated with PU. The highest oven-dry density values detected with BA+BX treated and PU coated Oriental beech specimens. PU coated Oriental beech specimens gave a higher oven-dry density values than that of EP coated wood specimens. While impregnation with FRC before PU coating caused to increase oven-dry density values of wood specimens, it generally decreased for FRC treated and EP coated wood specimens. For example, while oven dry- density value was 1.21g/cm^3 for PU coated wood, it was changed from 1.26 g/cm^3 to 1.32 g/cm^3 for FRC treated and PU coated wood. However, while oven dry density value was 0.76 g/cm^3 for only EP coated Oriental beech, it was changed from 0.72 g/cm^3 to 0.76 g/cm^3 for FRC treated and EP coated Oriental beech.

In Table 3, the air-dry density values of wood treated with FRC and coated with PU and EP resins are presented.

While the highest air-dry density value of Oriental beech was 1.34 g/cm^3 for treated with BA+BX and coated with PU, the minimum air-dry density value was 0.69 g/cm^3 for un-treated and non-coated wood. There was a statistical difference in air-dry density values between treated with FRC and PU coated groups and control groups. According to our results, PU coated Oriental beech specimens gave higher air-dry density values than EP coated Oriental beech specimens. While impregnation with FRC before PU coating caused to increase air-dry density values of Oriental beech specimens, it decreased for FRC treated and EP coated Oriental beech specimens. For example, while air-dry density value was 1.22 g/cm^3 for PU coated Oriental beech wood, it was changed from 1.27 g/cm^3 to 1.34 g/cm^3 for FRC treated and PU coated Oriental beech. However, while air-dry density value was 0.78 g/cm^3 for EP coated wood, it was changed from 0.71 g/cm^3 to 0.77 g/cm^3 for FRC treated and EP coated wood. Baysal et al. [21] studied oven-dry and air-dry density of borates treated and vinyl monomers coated wood. They found that oven-dry and air-dry density values of wood were highly increased statistical levels treated with solely vinyl monomer treatments and secondary vinyl monomer

Table 2. Oven-dry density values of Oriental beech treated with flame-resistant chemicals (FRC) and covered with PU and EP resins.

Chemicals	Retention (kg/m^3)	Oven-dry density values (g/cm^3)	Standard deviation	Homogeneity group
Control	-	0.65	0.01	D
PU	-	1.21	0.10	B
BA+PU	16.88	1.30	0.13	A
BX+PU	15.74	1.27	0.07	AB
AS+PU	14.67	1.26	0.17	AB
(BA+BX)+PU	13.96	1.32	0.07	A
EP	-	0.76	0.03	C
BA+EP	16.21	0.72	0.15	CD
BX+EP	16.07	0.76	0.04	C
AS+ EP	14.87	0.74	0.07	CD
(BA+BX)+ EP	16.05	0.76	0.05	C

PU: Polyurethane/Polyure; EP: Epoxy; BA: Boric acid; BX: Borax; AS: Ammonium sulphate. Each group received ten replicas. At a 95% confidence level, homogeneity was achieved in the group.

Table 3. Air-dry density values of Oriental beech treated with flame-resistant chemicals (FRC) and covered with PU and EP resins.

Chemicals	Retention (kg/m^3)	Air-dry density values (g/cm^3)	Standard deviation	Homogeneity group
Control	-	0.69	0.01	D
PU	-	1.22	0.10	B
BA+ PU	16.88	1.32	0.13	A
BX+ PU	15.74	1.28	0.07	AB
AS+ PU	14.67	1.27	0.17	AB
(BA+BX)+PU	13.96	1.34	0.07	A
EP	-	0.78	0.03	C
BA+EP	16.21	0.71	0.06	CD
BX+EP	16.07	0.77	0.03	CD
AS+EP	14.87	0.76	0.07	CD
(BA+BX)+EP	16.05	0.77	0.04	CD

PU: Polyurethane/Polyure; EP: Epoxy; BA: Boric acid; BX: Borax; AS: Ammonium sulphate. Each group received ten replicas. At a 95% confidence level, homogeneity was achieved in the group.

treatments on borates (P≤0.05). Geçer et al.[22] investigated oven-dry density values of Oriental beech pre-impregnated with boric acid and borax before styrene coated Oriental beech. They found that oven dry density values of Oriental beech were highly increased statistical levels impregnated with solely styrene coated and secondarily styrene coated on boric acid and borax (P≤0.05). In this context, the results obtained from the literature were similar to the results of this study.

Our results showed that boron compounds and ammonium sulphate showed same effects in terms of air-dry and oven-dry densities of wood.

3.2 Water absorption levels

Water absorption (WA) amounts of specimens treated with FRC [with 3% aqueous solution of BA, BX, and BA+BX and AS] and coated with PU and EP resins are presented in Table 4.

The finding were in line with the earlier finding[23] and showed that the untreated and uncoated control group's WA levels were significantly greater throughout the early phases of WA, notably within 1 and 8 h. It might be because water absorbed by wood at the beginning of soaking and reduced wood gaps with time[24]. Untreated and non-coated control specimens absorbed 25.53% of their weight in water after 1 hour, whereas PU and EP coated Oriental beech absorbed 0.90% and 3.46% water, respectively after 1 hour. Less water penetrates Oriental beech thanks to the hydrophobic properties of PU and EP shields, which also affect the wood's surface and any remaining water in the cell wall and lumen[25].

For all WA periods, the untreated and uncoated control group had the highest WA levels. While the WA level of the untreated and uncoated control group was 52.00% after 8 hours, it was 100.59% after 336 hours. The untreated and uncoated control groups thus received more than half of the total water in the 8-hour period. The WA levels of wood treated with BX and PU coated wood were the lowest during all other WA periods, with the exception of 1 h and 8 h. For all WA periods, PU coated wood specimens had lower WA levels than EP coated Oriental beech. The WA of PU-coated Oriental beech was 19.66% after 336 hours, whereas the WA of EP-coated Oriental beech was 48.36%. It may be claimed that the polyurethane/polyurea oligomers' backbones include more hydrophobic groups than epoxy oligomers do, and as a result, they serve to increase the crosslinked polymeric coating's water resistance while decreasing its water absorption capacity[25].

For all WA periods, there was a statistically significant difference in the WA levels between the control and treated and coated groups (p≤0.05). As for compared AS and boron chemicals usages as FRC, it has been determined that boron chemicals show higher activities when compared with AS in terms of water absorption levels. While, BX displayed lowest WA level with PU coated specimens, BA exhibited lowest WA level with EP coated specimens. Whereas, WA levels of AS treated and PU coated Oriental beech specimens were 18.34%, it was determined 10.96% for BX treated and PU coated Oriental beech specimens after 336 h WA period. As for EP coated specimens, it has been determined that WA levels of the AS treated Oriental beech specimens were 72.17%, and 52.50% for the BA treated wood specimens after 336 h WA period. Surprisingly, for EP coated Oriental beech, AS showed same effects with BA+BX in terms of WA levels after 336 h WA period. Moreover, they gave the worst results in terms of WA levels of Oriental beech after 336 h WA period. Usage of BX+BA mixture showed negative effect in terms of WA levels as compared with BX usage for EP coated Oriental beech. Geçer et al.[22] discovered that improving the water absorption levels of Oriental beech wood by impregnating it with various water-repellent compounds like styrene. Our findings agree with those of Geçer et al.[22] in their data.

4. Conclusions

Oriental beech treated with FRC [with 3% aqueous solutions of BA, BX, BA+BX, and AS] and coated with PU and EP resins were measured for oven-dry density, air-dry density, and water absorption levels.

Table 4. Water absorption levels of wood treated with flame-resistant chemicals (FRC) and covered with PU and EP resins.

Chemicals	Water absorption levels (%)													
	After 1 hour	H.G	After 8 hours	H.G	After 24 hours	H.G	After 72 hours	H.G	After 120 hours	H.G	After 168 hours	H.G	After 336 hours	H.G
Control	25.53	A	52.00	A	65.72	A	76.03	A	81.17	A	88.41	A	100.59	A
PU	0.90	B	3.11	C	4.40	D	8.96	E	9.95	E	13.06	F	19.66	F
BA+PU	1.14	B	2.18	C	3.72	D	8.17	E	9.63	E	11.07	F	15.29	FG
BX+PU	0.50	B	1.81	C	2.35	D	5.42	E	5.89	E	6.22	F	10.96	G
AS+PU	0.39	B	1.58	C	3.26	D	6.92	E	8.12	E	12.38	F	18.34	FG
(BA+BX) +PU	0.78	B	1.78	C	3.73	D	6.49	E	8.65	E	11.21	F	15.39	FG
EP	3.46	B	9.34	BC	18.53	C	32.09	D	35.19	D	39.48	E	48.36	E
BA+EP	5.50	B	16.29	B	25.55	BC	39.17	CD	43.17	CD	47.21	D	52.50	DE
BX+EP	4.51	B	11.82	B	31.19	B	47.36	B	49.18	B	56.96	BC	62.68	C
AS+EP	4.27	B	12.37	B	27.42	B	49.55	B	55.56	B	63.95	B	72.17	B
(BA+BX) +EP)	4.92	B	13.45	B	26.38	B	43.09	BC	47.46	BC	52.87	CD	73.07	B

PU: Polyurethane/Polyure; EP: Epoxy; BA: Boric acid; BX: Borax; AS: Ammonium sulphate. Each group received ten replicas. At a 95% confidence level. H.G.: Homogeneity group. Homogeneity was achieved in the group.

Oriental beech coated with PU and EP had statistically greater oven-dry and air-dry density values than the control group. The density might have risen as a result of Oriental beech wood absorbing PU and EP. Compared to EP coated Oriental beech specimens, our findings demonstrated that PU coated specimens gave higher oven-dry density and air-dry density values. While applying FRC before PU coating led to an increase in both density values for Oriental beech, it typically led to a drop in both density values for Oriental beech specimens coated with EP.

The WA of Oriental beech coated with EP and PU was found to be much lower than that of the control group. Meyer [26] asserts that a decrease in WA results from an increase in hydrophobicity. The bulking and water repellency properties of the PU and EP have a major role in the reduction of WA. It might be as a result of the capillaries' ability to diffuse water more slowly as a result of the addition of polymer[27]. For all WA periods, PU coated wood specimens had lower WA than EP coated wood specimens. The WA levels of FRC applied and PU coated Oriental beech specimens were lower than the WA levels of only EP coated Oriental beech specimens.The findings also support the notion that boron compounds (BA and BX) perform better as FRC than AS in terms of water absorption.

As a result, newly developed PU and EP coatings for wood could serve as substitutes for building materials where high physical qualities are required for outdoor use. The novel PU and EP coatings in this investigation have excellent physical characteristics, including as rising air-dry and oven-dry density values and falling wood water absorption levels.

5. Author's Contribution

- **Conceptualization –** İlknur Babahan Bircan.
- **Data curation –** Hilmi Toker.
- **Formal analysis –** Çağlar Altay.
- **Funding acquisition –** Ergün Baysal.
- **Investigation –** Hüseyin Peker.
- **Methodology –** Çağlar Altay.
- **Project administration –** Çağlar Altay.
- **Resources –** İlknur Babahan Bircan.
- **Software –** Hüseyin Peker.
- **Supervision –** Çağlar Altay.
- **Validation –** Ergün Baysal.
- **Visualization –** İlknur Babahan Bircan.
- **Writing – original draft** – Hilmi Toker.
- **Writing – review & editing** – Çağlar Altay.

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