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The Bending Strength Properties of Some Wood Types Impregnated With Fire Retardant Chemicals

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Abstract

This study has done in order to determine the effects of impregnation with fire retardant chemical materials on the bending strength of Oriental beech, European oak and Scotch pine wood materials. To achieve this goal, test samples prepared from woods of Oriental beech (*Fagus orientalis* Lipsky), European oak (*Quercus petraea* Lieb.) and Scotch pine (*Pinus sylvestris* Lipsky) according to TS EN 345 regulations were impregnated with ammonium-sulfate [$(NH_4)_2S04$], sodium acetate (NaC_2 $H3O_2.3H_2O$), aluminum chloride ($Al_2C_6.I_2H_2O$), borax [$Na_2B_4O_7.5H_2O$], boric acid [H_3BO_3] and, borax + boric acid (w:w=%50:50). The bending strength of impregnated samples were determined according to TS EN 408. Consequently, according to wood species; bending strength was found the highest value at Oriental beech (102,7 N/mm^2) and the lowest value at Scotch pine wood (86,72 N/mm^2). According to variety of impregnation; bending strength values were found no statistical difference between control samples and impregnated test samples. Considering the interaction of wood type and process; bending strength was found the highest value at beech + borax (112,90 N/mm^2) and the lowest value at pine + control samples (75,71 N/mm^2). In consequence, in the massive construction and furniture elements that the bending strength after the impregnation with borax is of great concern, Oriental beech wood materials could be recommended.

Key words: Bending strength, Fire retardant chemical materials, Impregnation, Woods

Yanmayı Geciktirici Kimyasal Maddelerle Emprenye Edilen Bazı Ağaç Malzemelerin Eğilme Direnci Özellikleri

Özet

Bu çalışma, yanmayı geciktirici kimyasal maddelerle emprenye etmenin doğu kayını, sapsız meşe ve sarıçam odunlarının eğilme direnci değerlerine etkilerini belirlemek amacıyla yapılmıştır. Bu amaçla, ülkemizde yaygın olarak bulunan, doğu kayını (*Fagus orientalis* Lipsky), sapsız meşe (*Quercus petraea* Lieb.) ve sarıçam (*Pinus sylvestris* Lipsky) odunlarından TS EN 345 esaslarına göre hazırlanan deney örnekleri Amonyum sülfat [(NH4)2S04], Sodyum asetat ($NaC_2H_3O_2.3H_2O$), Alüminyum klorür ($Al_2C_6.I_2H_2O$), Borax [Na_2B_4O7.5H2O], Borik Asit [H3BO3] ve Boraks + Borikasit (%50:50) ile emprenye edilmiştir. Emprenye edilen deney örneklerinde; eğilme direnci değerleri TS EN 408 esaslarına göre belirlenmiştir. Sonuç olarak ağaç türüne göre; eğilme direnci değeri en fazla kayında (102,7 N/mm^2) ve en az sarıçamda (86,72 N/mm^2) bulunmuştur. İşlem çeşidine göre; emprenye edilmiş deney örneklerinin eğilme direnci değerleri ile kontrol örnekleri arasında istatistiksel olarak bir fark bulunmamıştır. Ağaç türü + işlem çeşidine göre; eğilme direnci en fazla kayın + boraksta (112,9 N/mm^2) ve en az sarıçam + kontrolde (75,71 N/mm^2) bulunmuştur. Bu çalışmayla, eğilme direnci önemli olduğu kullanım alanlarında boraks ile emprenye edilmiş Doğu kayını ağaç malzeme tercih edilebilir.

Key words: Eğilme direnci, Yanmayı geciktirici kimyasallar, Emprenye, Ağaç malzeme

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1. Introduction

Wood is an environmentally desirable material for fiber and structural use. It is efficient in both economic and environmental costs to users. To extend its utility into new markets, wood is sometimes treated with chemicals [1]. One of the major objections to the use of wood for many purposes is of course the question of its long-term resistance to the natural processes of degradation, particularly at sites and in situations where there is high biological hazard and where no form of chemical or physical protection is afforded to the material. With an increased demand for timber worldwide and moves towards fast-grown plantation species, the need to impart additional protection, usually in the form of chemical treatment, has become necessary to confer long-term performance in these wood products [2]. In case wood is not impregnated but only painted and varnished instead, the prevention on the surfaces is limited to a maximum of two years [3].

It is reported that, in mines, as a result of the impregnation of the beech and spruce wood with water-soluble salts, the bending, tensile and impact strength decreased a little whereas compression strength increased [4]. In another research concerning the impregnation of pine, spruce, fir, beech and poplar woods with Antrasen, it was found that, the compression strength increased by 6-40 % and bending strength increased by 10-22 % [5]. In the impregnation of pine and beech wood with UA salts and tar oil, the tar oil increased compression strength by 10 % and UA salts increased with a small rate. On the other hand, the tar oil increased the bending strength whereas the UA salts diminished the bending strength. [6].

Vologdin declared that, among the materials used for the impregnation of pine; Sodium pentaclorfenet, Cupper sulphate and Sodium fluoride increased the compression strength respectively by 95 %, 25 % and 3 % whereas Zinc chloride decreased the compression strength by 9%. Sodium pentaclorfenet also increased the bending strength [7]. In another study, pressure treatment caused to a decrease of 8-10 % in the bending strength of different wood types [8].

It was assessed that, salty impregnation materials increased the compression strength by 4.6-9.6 %, whereas decreased the bending strength by 2.9-16 % [9]. After the impregnation of pine wood samples by hot-cold open tank method with eleven preventives, no significant difference was observed in the bending strength except the decreasing effects of fluotox containing acid florid [10]. In another study, chromate copper arsenate (CCA) and arsenate copper arsenate (ACA) salts did not caused any significant impact on modulus of elasticity in bending [11].

Fire retardant chemicals can also reduce the strength of lumber or plywood, an effect related to the nature of the chemicals and to the re-drying temperatures used in the treating process [12].

In this study, Oriental beech, European oak, Scotch pine woods commonly being used in furniture manufacturing and massive constructions were examined with respect to the effects of impregnation with fire retardant chemical materials on the bending strength of Oriental beech, European oak and Scotch pine wood materials.

2. Materials and Methods

2.1. Materials

2.1.1. Solid Woods

The solid woods to be used as test samples were randomly selected from the timber merchants of Ankara. Specific pains were taken for the selection of wood materials. Accordingly, non-deficient, proper, knotless, normally grown (without zone line, without reaction wood and without decay, insect mushroom damages) wood materials were selected.

2.1.2. Protective Chemicals

In this study, preservative chemicals; borax, boric acid, boric acid + borax (w:w=%50:50) ammonium sulfate, sodium acetate, aluminum chloride, are used to impregnate the test samples. Borax and boric acid were obtained from Etibank-Bandırma (Turkey) borax and acid Factory. Boric acid [H_3BO_3] contains %56.30 ½ B_2O_3 %43.7 H_2O with a molecular weight 61.84, density 1.4 $g.cm^{-3}$, melting point 171 ^{0}C. Borax [$Na_2B_4O_7.5H_2O$] contains %21.28 Na_2O %47 B_2O_3, %30.9 H_2O with a molecular weight 291.3, density 1.8 g/cm^3, melting point 741 ^{0}C [13]. Ammonium sulfate ($(NH_4)2SO_4$) is the molecular weight of 132.14, decompose above °C 280. Aqueous solution shows weak acid functionality. Aluminum chloride ($AlCl_3$+3KCl+Al) is density of 2.698 g/cm^3 at 25 °C, a melting point of 659.7 °C boiling point is 2057 °C. Sodium acetate ($C_2H_3NaO_2$) is obtained from the reaction of acetic acid, sodium carbonate or sodium hydroxide. There are 58 ^{o}C water lost trihydrate and anhydrous forms. Water-soluble and ethoxyethyl Zealand; slightly soluble in ethanol [14].

2.2. Methods

2.2.1. Determination of density

The densities of wood materials, used for the preparation of test samples were determined according to TS 2472 [15]. For determining the air-dry density, the test samples with a dimension of 20x30x30 mm were kept under the conditions of 20±2 ^{0}C temperature and 65±3 % relative humidity until they reached to a stable weight. The weights were measured with an analytic scale of ±0.01g sensitivity. Afterwards, the dimensions were measured with a digital compass of ±0.01mm sensitivity. The air-dried densities (δ_{12}) of the samples were calculated by the formula;

$$\delta_{12} = \frac{W_{12}}{V_{12}} \ g.cm^{-3} \qquad [1]$$

Where W_{12} is the air-dry weight (g) and V_{12} is the air-dry volume (cm^3). The samples were kept at a temperature of 103±2 ^{0}C in the drying oven until they reached to a stable weight for the assessment of oven-dry density. Afterwards, oven-dry samples were cooled in the desiccator containing phosphorus pentoxide (P_2O_5). Then, they were weighted on a scale of ±0.01g sensitivity and their dimensions were measured with a digital compass of ± 0.01mm sensitivity. The volumes of the samples were determined by stereo metric method and the densities (δo) were calculated by the formula;

$$\delta o = \frac{Wo}{Vo} \ g.cm^{-3} \qquad [2]$$

Where Wo is the oven-dry weight (g) and Vo is the oven-dry volume (cm^3).

2.2.2. Determination of humidity

The humidity of test samples before and after the impregnation process was determined according to TS 2471 [16]. Thus, the samples with a dimension of 20x20x20 mm were weighed and then oven-dried at 103±2 ^{0}C till they reach to a constant weight. Then, the samples were cooled in desiccator containing phosphorus pentoxide (P_2O_5) and weighed with an analytic scale of 0.01 g sensitivity. The humidity of the samples (*r*) was calculated by the formula;

$$r = \frac{Mr - Mo}{Mo} x\ 100 \qquad [3]$$

Where *Mr* is the initial weight (g) and *Mo* is the oven-dry weight (g).

2.2.3. Preparation of the test samples

The rough drafts for the preparation test and control samples were cut from the sapwood parts of massive woods and conditioned at a temperature of 20±2 ^{0}C and 65±3 % relative humidity for three months until reaching an equilibrium in humidity distribution. The samples for bending strength test, with a dimension of 20x20x400 mm were cut from the drafts having an average humidity of 12 % according to TS EN 408 [17]. The densities and humidity values of all test samples were measured before the impregnation process. The test samples were impregnated according to ASTM D 1413 [18], TS 344 [19] and TS 345 [20]. The samples were dipped in the impregnation pool immersing 1 cm below the upper surface for 2 hours for medium-term dipping. The specifications of the impregnation solution were determined before and after the process. The processes were carried out at 20±2 ^{0}C temperature. Retention of impregnation material (*R*) was calculated by the formula;

$$R = \frac{G.C}{V} 10^3\ kg.m^{-3} \qquad G = T_2 - T_1 \qquad [4]$$

Where *G* is the amount of impregnation solution absorbed by the sample (g), T_2 is the sample weight after the impregnation (g), T_1 is the sample weight before the impregnation (g), *C* is the concentration (%) of the impregnation solution and *V* is the volume of the samples (cm^3). Impregnated test samples were kept under a temperature of 20±2 ^{0}C and 65±3 % relative humidity until they reach to a stable weight.

2.2.4. Determination of Bending Strength

Perpendicular to the fiber line (⊥) bending strength tests was carried out with the Universal Testing Equipment shown in Fig.1, according to TS EN 408.

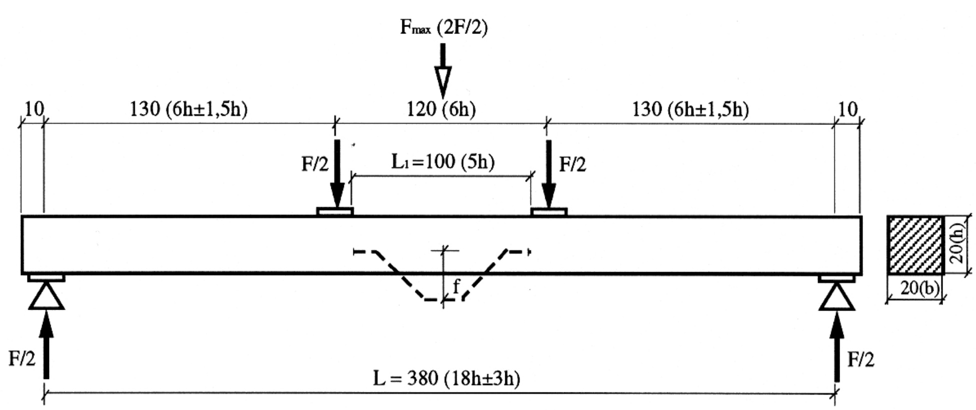

Figure 1. Test equipment for bending strength (dimensions in mm)

The capacity of the Universal Testing Equipment was 400 N. The speed of the test machine was adjusted to 5 mm/min. for breakage to occur in 1-2 minutes. Bending strength was calculated with the following equations.

$$\sigma_b = \frac{3F\max.(L - l_1)}{2bh^2} \text{ (N/mm}^2\text{)} \qquad [5]$$

Where, F_{max} is the breaking load on the scale (N), L is distance between the lower tension rods (mm), l_1 is distance between two loads (mm), b is the cross-sectional width of test sample (mm), h is the cross-sectional thickness of the test sample (mm) [21].

2.3. Data Analysis

A total of 99 samples (3 x 3 x 11) were prepared. The effects of wood material and impregnation method on the modulus of Elasticity in Bending were analyzed by Analysis of Variance. Duncan's Multiple Range Test was also applied where appropriate.

3. Results and Discussion

3.1. Density

Statistical values of average air-dried densities that are used in the experiments samples have been shown in Table 1.

Tab.1. Statistical values of air-dried density averages

Statistical values	WOOD TYPES		
	Beech	Oak	Pine
X *($g.cm^{-3}$)*	0.692	0.665	0.573
Ss *($g.cm^{-3}$)*	0.01961	0.02368	0.01305
v *(s^2)*	0.00042	0.00062	0.00019
min *($g.cm^{-3}$)*	0.648	0.624	0.552
max *($g.cm^{-3}$)*	0.715	0.695	0.595
N	10	10	10

X: Arithmetic mean, v: Variance, Ss: Standard deviation, N: Number of samples

According to the Tab.1 the highest air-dried density value was found in beech and the lowest in pine wood. The air-dried density values of massive wood materials in literature; Ash (0.690 $g.cm^{-3}$), beech (0.660 $g.cm^{-3}$), oak (0.650 $g.cm^{-3}$), walnut (0.680 g/cm^3), pine (0.520 $g.cm^{-3}$), poplar (0.502 $g.cm^{-3}$) [22]. These values have shown parallelism with air-dried density values of experimented wood materials.

3.2. Retention Amount

The results of multiple variance analyses with regard to the effects of wood type and impregnation chemicals are given in Table 2.

Tab. 2. The results of analysis of variance for retention amounts

SOURCE	Degrees of freedom	Sum of square	Means of square	F value	Sig. $\alpha \leq 0.05$
Wood types (A)	2	4224.239	2112.120	71.0438	0.0000
Process (B)	5	4167.535	833.507	28.0360	0.0000
Interaction AB	10	2238.093	223.809	7.5281	0.0000
Error	162	4816.234	29.730		

The results of the analysis of variance indicated that the effects of the wood types, impregnation chemicals and their interaction were found to be statistically significant ($\alpha \leq 0.05$). Average values the retention amounts of different types of wood and types of process are given in Tab. 3.

Tab. 3. Average the retention amounts of different types of wood and types of process (kg/m³)

WOOD TYPES	X	HG
Pine (I)	19.39	A
Beech (II)	18.60	A
Oak (III)	8.74	B
IMPREGNATION CHEMICALS	X	HG**
Borax (Bx)	22.70	A
Borax + Boric acid (Bx+Ba)	19.77	B
Sodium acetate (Sa)	17.90	B
Boric acid (Ba)	12.46	C
Aluminum chloride (Ac)	10.37	C
Ammonium sulfate (As)	10.26	C

X: Average value, HG: Homogeneous group, *LSD: ±1,964, **LSD: ±2,778

As shown in Tab. 3, according to types of wood highest retention amount was obtained in pine (19.39 kg/m³) and the lowest in oak (8.74 kg/m³) wood samples. This situation could be attributable to the impact of permeability of pine wood and due to tyloses in oak wood samples. According to impregnation chemicals, highest retention quantity was obtained in Bx (22.70 kg/m³) and the lowest in As (10.26 kg/m³). This may be due to chemical properties of Bx and As. The Duncan test results of the interaction of wood type and impregnation chemicals are shown Tab.4 and the graphic is shown in Figure 2.

Tab.4. The Duncan test results of the interaction of wood type and impregnation chemicals

TYPE OF WOOD - PROCESS	X	HG	TYPE OF WOOD - PROCESS	X	HG
Pine (I)–Bx	32.67	A*	Beech (II) –Ba	18.04	CDE
Pine (I)–Bx+Ba	28.90	A	Beech (II) –Ac	16.14	DEF
Pine (I)–Sa	23.69	B	Beech (II) –As	12.58	FGH
Pine (I)–As	11.84	FGHI	Oak (III) –Bx	13.39	EFG
Pine (I)–Ba	11.41	FGHI	Oak (III) –Bx+Ba	9.316	GHI
Pine (I)–Ac	7.844	GHI	Oak (III) –Sa	8.339	GHI
Beech (II) –Bx	22.05	BC	Oak (III) –Ba	7.938	GHI
Beech (II) –Sa	21.68	BC	Oak (III) –Ac	7.117	HI
Beech (II) –Bx+Ba	21.10	BCD	Oak (III) –As	6.355	I**

LSD : ± 4.812, * : the highest, **: the lowest

According to interaction of wood type and impregnation chemicals highest retention amount was obtained in pine impregnated with Bx (32.67 kg/m³) and the lowest in oak impregnated with As (6.355 kg/m³) samples.

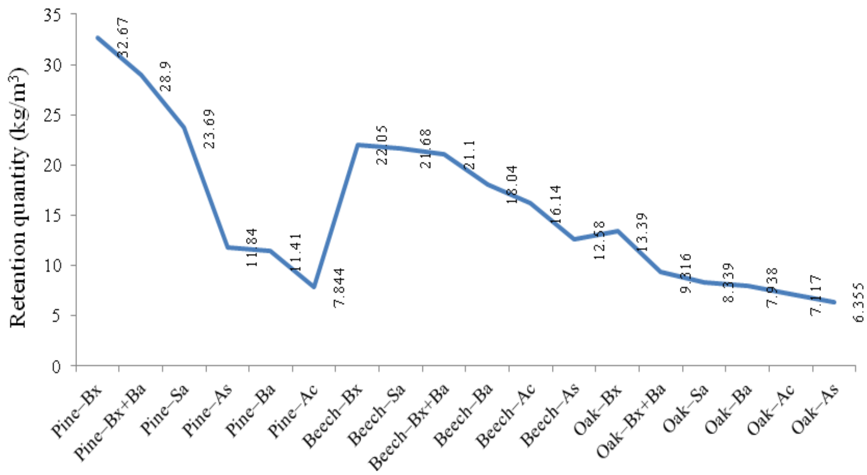

Figure 2. The retention amount of the interaction of wood type and impregnation chemicals

3.3. Bending Strength

The results of multiple variance analyses with regard to the effects of wood type and impregnation chemicals for bending strength are given in Tab 5.

Table 5. The results of analysis of variance for bending strength

SOURCE	Degrees of Freedom	Sum of Square	Means of Square	F Value	Sig. $\alpha \leq 0{,}05$
Types of wood (A)	2	8979,773	4489,887	9,3398	0,0001*
Types of process (B)	6	623,189	103,865	0,2161	
Interaction AB	12	10316,918	859,743	1,7884	0,0525
Error	189	90857,612	480,728		

The results of the analysis of variance indicated that the effects of the wood types, impregnation chemicals and their interaction were not found to be statistically significant ($\alpha \leq 0.05$). The average bending strength values of different types of wood and types of process are given in Tab. 6.

Tab. 6. Average the bending strength values of different types of wood and types of process (N/mm^2)

WOOD TYPES	X	HG*
Beech (II)	102,70	A
Oak (III)	94,62	B
Pine (I)	86,72	C
IMPREGNATION PROCESS	X	HG**
Bx	97,79	A
Kn	96,58	B
Sa	94,40	C
Ba	94,35	DE
Bx+Ba	93,78	EF
Af	93,52	F
Akl	92,41	G

X: Average value, HG: Homogeneous group, *LSD : ± 7,306, **LSD: ± 11,16

As clearly shown in Table 6, according to types of wood the highest bending strength value was obtained in beech (102,70 N/mm^2) and the lowest in pine (86,72 N/mm^2) wood. According to impregnation process, the highest bending strength value was obtained in Bx (97,79 N/mm^2) and the lowest in Akl (92,41 N/mm^2). The Duncan test results of modulus of elasticity in bending of the interaction of wood type and process are shown Tab.7 and the graphic is shown in Fig. 2.

Tab.7. The Duncan test results of the interaction of wood type and process

TYPE OF WOOD AND PROCESS	X	HG
Scotch Pine (I)–Sa	96,43	ABCD
Scotch Pine (I)–Akl	95,83	ABCD
Scotch Pine (I)–Bx+Ba	90,35	ABCD
Scotch Pine (I)–Af	87,79	BCD
Scotch Pine (I)–Bx	84,73	CD
Scotch Pine (I)–Ba	76,18	D
Scotch Pine (I)–Kn	75,71	D**
Oriental Beech (II)–Bx	112,9	A*
Oriental Beech (II)–Kn	109,5	AB
Oriental Beech (II)–Af	103,9	ABC
Oriental Beech (II)–Sa	100,8	ABC
Oriental Beech (II)–Ba	100,3	ABC
Oriental Beech (II)–Bx+Ba	97,95	ABCD
Oriental Beech (II)–Akl	93,69	ABCD
European Oak (III)–Ba	106,6	ABC
European Oak (III)–Kn	104,5	ABC
European Oak (III)–Bx	95,71	ABCD
European Oak (III)–Bx+Ba	93,03	ABCD
European Oak (III)–Af	88,84	BCD
European Oak (III)–Akl	87,70	BCD
European Oak (III)–Sa	85,97	BCD

LSD: ±1851, *: the highest, **: the lowest

According to interaction of wood type and impregnation chemicals the highest bending strength value was obtained in impregnated Oriental beech with Bx (112,9 N/mm^2) and the lowest in control Scotch pine (75,71 N/mm^2) samples.

Figure 2. The Bending strengt of the interaction of wood type and process

4. Conclusion

The retention amounts were found different depending on wood type and impregnation materials. According to types of wood highest retention amount was obtained in pine wood (19.39 kg/m³ - 21.81%) and the lowest in oak wood samples (8.742 kg/m³ -9.15%); according to impregnation chemicals highest retention amount was obtained in Bx (22.70 kg/m³) and the lowest in As (10.26 kg/m³). According to interaction of wood type and impregnation chemicals highest retention amount was obtained in pine impregnated with Bx (32.67 kg/m³) and the lowest in oak impregnated with As (6.355 kg/m³) samples. Accordingly, the highest values were obtained in pine samples. This case may be due to structural properties of pine wood. In the literatüre, Özçiftci and Batan [23] reported that retention amount of Scotch pine higher than Uludag fir and Oriental beech.

Bending strength; according to wood types the highest bending strength value was obtained in beech (102,70 N/mm^2) and the lowest in pine (86,72 N/mm^2) wood. Depending on the species of impregnation chemicals, the highest bending strength (97,79 N/mm^2) and the lowest in Akl (92,41 N/mm^2). According to interaction of wood type and impregnation chemicals the highest bending strength value was obtained in impregnated Oriental beech with Bx (112,9 N/mm^2) and the lowest in control Scotch pine (75,71 N/mm^2) samples. According to this, it can be said that, Bx showed an increasing effect on the bending strength compared to the control samples, however other impregnation chemicals showed reducing effect on the bending strength. In general, impregnation chemicals showed an increasing effect on pine wood, however decreasing effect showed on beech and oak wood, excluding Bx for beech. Consequence, in the massive construction and furniture elements that the bending strength after the impregnation with borax is of great concern, Oriental beech wood materials could be recommended.

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