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Original Article

Physical and mechanical properties of wood impregnated with quebracho and boron compounds

Kebrako ve borlu bileşikler ile emprenye edilen ahşap malzemenin fiziksel ve mekanik özellikleri

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ABSTRACT

In recent years, alternative natural impregnation materials are being sought as substitutes for chemical impregnation materials used for conserving wooden materials; therefore, such natural materials have acquired significance in the forest products industry. In this study, the boron compounds borax and boric acid, which are abundant raw materials in Turkey, and quebracho, a natural impregnation material, were used. For the impregnation process, aqueous solutions of 1%, 3%, and 5% boron compounds were utilized. The test samples were impregnated according to ASTM D 1413-76 principles. Oven-dry density, retention rate, bending strength, elastic modulus, compression strength parallel to fibers, bonding strength parallel to fibers, and screw holding strength tests of the impregnated samples were measured, and the results were compared with those of control samples. The retention, oven-dry density, comprehension parallel to fibers, and screw holding strength of the samples were found to be higher than those of the control samples, whereas bending strength, elastic modulus, and bonding strength parallel to fibers were lower. After impregnation, it was observed that there was a decline in strength values and a rise in retention rates with the increase in the concentrations of boron compounds. The values for samples impregnated with borax were higher than those for the samples impregnated with boric acid.

Keywords: Boron compounds, impregnation, natural impregnation materials, oriental beech, quebracho

ÖZ

Son yıllarda orman ürünleri sanayisinde önemli bir yer işgal eden ahşap malzemelerin korunmasında kullanılan kimyasal emprenye maddelerinin yerine alternatif doğal emprenye maddeleri aranmaktadır. Bu çalışmada, Ülkemizde hammadde olarak bol bulunan borlu bileşikler (boraks ve borik asit) ile doğal emprenye maddelerinden olan kebrako kullanılmıştır. Emprenye işleminde borlu bileşiklerin %1, 3 ve 5'lik sulu çözeltileri kullanılmıştır. Deney örneklerinin emprenyesi ASTM D 1413-76 esaslarına göre yapılmıştır. Emprenyeli örneklerin tam kuru yoğunluk, retensiyon miktarı, eğilme direnci, elastikiyet modülü, liflere paralel basınç direnci, liflere paralel yapışma direnci ve vida tutma direnci testleri yapılarak kontrol örnekleri ile kıyaslanmıştır. Sonuç olarak, yapılan testler sonucunda retensiyon, tam kuru yoğunluk, liflere paralel basınç ve vida tutma dirençleri kontrol örneklerinden daha yüksek çıkmıştır. Eğilme direnci, elastikiyet modülü ve liflere paralel yapışma dirençleri ise kontrol örneklerinden daha düşük çıktığı tespit edilmiştir. Emprenye sonrası deney örneklerinde borlu bileşiklerin konsantrasyonları arttıkça direnç değerlerinde düşüş, tam kuru yoğunluk ve retensiyon miktarlarında ise artış görülmektedir. Borlu bileşiklerden boraks ile emprenye edilen örneklerde değerler borik asit ile emprenye edilenlerden daha yüksek çıkmıştır.

Anahtar Kelimeler: Borlu bileşikler, doğal emprenye maddeleri, doğu kayını, emprenye, kebrako

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INTRODUCTION

Wood as used in various areas is the only natural renewable raw material that doesn't damage the environment. The physical and mechanical properties of wood, its anatomic structure and chemical composition enable it to be used in a wide variety of products (Bozkurt and Erdin, 1997). Use

of wooden materials has been sustained since the dawn of humankind. An organic living creature, wood is utilized in many areas and its use is increasing day by day. Some of the reasons for the use of wood in so many areas are: its high strength despite its lightness, its anatomic structure, its easily processable nature, its ability to hold screw and nail (Aslan, 1998; Hafızoğlu et al., 1994; Baysal, 1994). In addition to its many favourable features as stated above, it has certain undesirable properties. As an organic material, its inflammability, its natural vulnerability to destruction by insects and to decomposition by fungus, the fact that its size changes according to equilibrium humidity depending on the relative humidity & temperature of the weather, and its fading colour under the sun's rays are considered to be undesirable features of the wooden material.

Mankind understood that wooden materials need to be preserved in their usage areas centuries ago and thereby they started to take various precautions for this purpose. Archaeological excavations and inspections carried out on the ribs of sunken ships have revealed that the partial carbonization of the wood was one of the first precautions that was taken to preserve wooden materials 4000 years ago (Huş, 1977). Even though some wooden materials possesses a natural durability and show stability and strength in the face of external effects thanks to their own anatomic and chemical structure, they cannot endure outside weather conditions for a long period of time. Therefore, wooden materials are impregnated with several chemical substances, surface treatments are applied with various layering and preservative substances appropriate for usage area, or it is protected with non-chemical constructive precautions (natural, biological and alternative wood conservation) (Kurtoğlu, 1984). According to usage area, some processes like drying, impregnation and surface treatments are applied to increase the usage life of wooden materials by making them more durable against physical, chemical and biological factors. The most commonly applied protection method for wooden materials is to treat them with an appropriate chemical and method according to usage area Şen and Hafızoğlu, 2001). In the event that the wooden material is used without treating with such chemical substances with respect to its usage area, it is damaged due to impacts like insect, fungi, dampness, fire etc. Thereupon, it requires repair, replacement and maintenance expense to avoid the early end of its economic life (Richardson, 1987; Yalınkılıç et al., 1995). With the intention of preventing the destruction of the wood by biological pests, it has been determined that impregnation with boron compounds will extend usage life with experiments (Winandy, 1990).

It is agreed that Boron compounds are the only impregnation material that demonstrates both insecticide and fungicide properties against insects and fungi destroying wooden materials. Boron compounds can also be used effectively against pests like termites and insects at the same time. When compared with traditional impregnation substances, boron compounds are responsible for lower levels of environmental damage, causing very small amounts of acute toxicity. Boron compounds are no more toxic than common salt to humans and animals, and they are colourless and odourless. They don't have corrosive effects and they are resistant to combustion. Nowadays, boron compounds are accepted as one of the safest chemicals utilized as a preservative impregnation substance. Since their negative effects on humans and environment are at minimum levels, their use is gaining more and more importance. Because they have less toxic properties than other impregnation materials containing heavy metals, boron compounds are considered to be the most significant impregnation materials of the future. Apart from their activities against pests like fungi and termites, usage areas of boron compounds multiply thanks to increasing the resistance to combustion (Lloyd, 1998; Kartal and Green, 2002; Yaşar and Atar, 2017).

Some boron compounds used in both the commercial sense and scientific testing with the purpose of wood protection, are boric acid, borax, sodium perborate, magnesium borate, ammonium borate, diammonium octaborate, triethyl borate, ammonium pentaborate, zinc fluorate, ammonium fluoborate, disodium octaborate and copper metaborate (Karayazıcı et al., 1980). Boron compounds are applied to solid wooden materials in impregnation processes with many compressed and unpressurised procedures.

There are tannins which have the potential to be used as biopreservatives. The word tannin is a rather broad term and covers compounds in various chemical compositions. Tannins have significant importance among phenolic substances which make up of 20-30% of wood. The most important part of phenolic substances is made up of a system known as lignin. Tannins are phenolic compounds that can be dissolved in phlobaphene and are a coloured substance, and lignin can be dissolved in water and organic solvents (Hafızoğlu, 1984). Tannins are amorphous substances and they also known as tannic acid. Their colours vary between light straw and dark mahogany. Tannins are water-soluble polyphenolic compounds, which are found intensely in high-rise structured trees like chestnut, oak, acorn, and sumac, their chemical structure varies widely and their molecular weight can reach up to 20000 daltons. Tannins, which can be found in bark, roots, leaves, fruit and seed parts of plants, display visual characteristics ranging from light yellow to white in colour, from shiny to matt and they have loose structured acrid tasting compounds (Khanbabaee and Ree, 2001). Tannins are found in many barks, some coniferous tree types, chestnut and oak trees. Tannins have protective features against fungal diseases of wood (Kırcı, 2000).

Impregnation is the process applied by various methods with the purpose of protection of wooden material, an anisotropic material, against numerous biotic and abiotic issues (Bozkurt and Erdin, 1997). The success and protection level of the impregnation process depends on the net dry impregnations substance adhesion to the wood (retention) and the penetration depth of the impregnation substance in the wood, along with the impregnation substance and the characteristics of the wood (Baysal et al., 2003). The natural durability classifications of wooden material according to weight loss: less than 5 years are referred as nondurable, between 5 and 10 years are less durable,

between 10 and 15 years are moderate durable, between 15 and 20 years are durable, and 25 years and more are categorized as very durable class (Bozkurt et al., 1993). On the determination of this duration, the chemicals used in the impregnation process are as important as the properties of the wooden material. Each chemical used has different characteristics and impact areas. Therefore, the most suitable impregnation material for each condition should be chosen bearing in mind the impacts which will be encountered in the usage locations of the wooden materials (Yalınkılıç et al., 1995).

The purpose of this study, is to attempt to reduce the damage and adverse affects occurring in the environment as a consequence of impregnation processes utilizing boron compounds through the use of natural impregnation materials which do not harm nature.

MATERIALS AND METHODS

Material

In this study, the oriental beech, which is frequently used in indoor applications and has a wide distribution in Turkey, is used as a sample material. The oriental beech used in the preparation of samples was grown in the province of Gümüşhane in the Kürtün district in Alacadağ at about 1200 m altitude. Test samples were prepared from parts of the wood without defects (paying attention to fiber direction) and they were then dried until they reached air-dried moisture gradient (12%).

Quebracho, which contains plenty of tannins and is readily available commercially, is used as a natural impregnation substance. Quebracho extract is dark coloured and contains tannin in a ratio of 80% (Figure 1). The colour darkens with contact with light. Quebracho settles quite easily. Its natural pH value is 4,9 (URL-1, 2015).

Table 1. Size and standards of test samples used for determining of the physical properties

Number	Test Name	Dimensions (mm)	Standard
1	Retention	20 x 20 x 30	[1]ASTM D 1413–07
2	Oven-Dry Density	20 x 20 x 30	[2]TS2472

[1]ASTM: American society for testing and materials; [2]TS: Turkish standards

Quebracho was used in the impregnation process and the solution was prepared first. The solution was prepared by dissolving 5% mineral tannin in water with respect to weight quantity. The impregnation mix was prepared by adding boron compounds (in a concentration suitable for the conducted impregnation process), to the solution. Boron compounds borax (B) and boric acid (BA) were used in aqueous solutions in concentrations of 1, 3 and 5%. In the impregnation process, mixtures of natural impregnation materials and boron compounds were applied. The boron compounds used in the study was supplied by Kırka, Bigadiç and Emet facilities affiliated to Eti mining works.

Method

The Preparation of Samples

Oriental beech (*Fagus orientalis* L.) samples are prepared in accordance with TS standards at the Gümüşhane University Gümüşhane vocational school of higher education furniture and decoration workshop. For each test (retention, oven dry density, bending strength, elastic modulus, bonding strength parallel to fibers, screw holding strength, compression strength parallel to the fibers), 10 samples for each were prepared to use in the study with a total of 420 samples. Test samples were prepared, paying attention to fiber direction and that there weren't any flaws in the wood samples. Any samples not in accordance with required standards or having flaws were isolated and excluded. In this way, the aim was to prevent any errors that might have originated from flaws in the wood samples.

Applied test standards and dimensions of wooden material used in the determination of physical features are given in Table 1 and sample numbers tested are given in Table 2.

Applied experiment methods and dimensions of wooden material used in the determination of mechanical properties are given in Table 3 and sample number is given in Table 4.

Figure 1. Extract and wood of quebracho

Table 2. Amount of test samples used for determining of the physical properties

Physical Properties	Wood Species	Natural Impregnation Materials	Boron Compounds	Concentration (%)	Sample Numbers
Retention	Oriental beech	Qebracho	Boraks	1	p.p.[1]xw.s.[2].xn.i.m.
Oven-Dry Density			Borik asit	3	[3]xb.c[4].xc[5]xr[6]
				5	2x1x1x2x3x10=120

[1]p.p.: physical properties; [2]w.s.: wood species; [3]n.i.m.: natural impregnation materials; [4]b.c.: boron compounds; [5]c: concentration; [6]r: repetition

Table 3. Size and standards of test samples used for determining the mechanical properties

Number	Test Name	Dimensions (mm)	Standard
1	Bending Strength	20 x 20 x 360	TS 2474
2	Elastic Modulus	20 x 20 x 360	TS 2478
3	Compression Strength Parallel to the Fibers	20 x 20 x 30	TS 2595
4	Screw Holding Strength Tests	50 x 50 x 20	TSEN 13444
5	Bonding Strength Parallel to Fibers	20 x 15 x 150	[1]DIN 53225

[1]DIN: Deutsches institut für normung

Table 4. Amount of test samples used for determining the mechanical properties

Mechanical Properties	Wood Species	Natural Impregnation Materials	Boron Compounds	Concentration (%)	Sample Numbers
Bending Strength	Oriental beech	Qebracho	Borax	1	m.p.[1]xw.s.[2].xn.i.m.
Elastic Modulus			Boric Acid	3	[3]xb.c[4].xc[5]xr[6]
Compression Strength P.F.				5	5x1x1x2x3x10= 300
Screw Holding Strength					
Bonding Strength P.F.					

[1]m.p.: mechanical properties; [2]w.s.: wood species; [3]n.i.m.: natural impregnation materials; [4]b.c.: boron compounds; [5]c: concentration; [6]r: repetition

Table 5. Amount of impregnate

Wood Species	Natural Impregnation Materials + Boron Compounds + Concentration	Impregnation Number
Oriental beech	Qebracho + Borax + 1%	1
	Qebracho + Borax + 3%	1
	Qebracho + Borax + 5%	1
	Qebracho + Boric Acid + 1%	1
	Qebracho + Boric Acid + 3%	1
	Qebracho + Boric Acid + 5%	1

Impregnation Process

In this study, a total 6 impregnation process were conducted (Table 5). Cell method was chosen in compliance with ASTM D 1413 principles.

The samples prepared in impregnation process first were subjected to pre-combustion for 30 minutes in the impregnation mechanism, later to impregnation treatment for 30 minutes under pressure of 10 bars (Figure 2). The samples extracted from the impregnation mechanism were kept at a temperature of 20±2 ˚C and in a relative humidity of 65% for conditioning for a week and ensured to reach an equilibrium humidity of 12%. For the determination of retention and oven dry density, the samples were brought to oven dry condition again after impregnation and the essential measurements were carried out. Afterwards, the physical and mechanical tests were carried out on the oven dry samples. After impregnates samples, control samples were subjected to testing and the results were compared statically (Adanur, 2015).

The Determination of Physical Properties

Retention Rate

The impregnation of test samples was carried out according to ASTM D 1413–07 principles. The retention rate (R, kg/m^3) of test samples was calculated using the following equation (Bektaş, 1997):

$$R = \frac{G \times C}{V} \times 10^3 \ (kg/m^3)$$


Figure 2. Impregnating device employed in the impregnation process

In this equation;
G = T2 - T1
T1 : the weight of test samples before impregnation (g)
T2 : the weight of test samples after impregnation (g)
V : Sample volume (cm^3)
C : solution concentration (%)

The Determination of Oven-Dry Density

In the experiment to identify oven-dry density, the principles stated in TS 2472 standard were taken into consideration, wooden materials were prepared in sizes of 20x20x360 mm in accordance with the standard, then they were put in the drying oven. The temperature was gradually raised to 50 ºC, 75 ºC and 103 ± 2 ºC, the samples were kept until their weight reached stability and the samples were brought to an oven dry condition. The samples taken from the drying oven were permitted to cool down by placing in the desiccator with silicon dioxide (silica gel), weighed in an analytic scale with a sensitivity of ±0.01 g, (M_0) value and their sizes were measured using a digital caliper with a sensitivity of ±0.01 g, and their volumes were calculated. The oven dry densities (D_0) were calculated using the equation below (Bektaş, 1997).

$$D_o = \frac{M_o}{V_o} \ (g/cm^3)$$

In this equation;
D_0 : The density in oven dry humidity (g/cm^3)
M_0 : The weight of sample in oven dry humidity (g)
V_0 : The volume of sample in oven dry humidity (cm^3)

The Determination of Mechanical Properties

The Determination of Bending Strength

For determination of bending strength, the principles stated in TS 2474 (1976) standard were followed and the test samples were prepared in 20x20x360 mm sizes in accordance with these standards. The dimensions of the test samples were determined by measuring with a digital caliper with a sensitivity of ±0.01 g. The distances between the midpoints of the cylindric fulcrums, where the test items were placed, were set at 15 times (15x20 mm = 300 mm) the thickness of the test item. Loading was conducted uniformly with a constant fixed speed on the surface of the test item. The loading speed was set to 6 mm/min. Test speeds were set so that the test items would break after 1.5 ± 0.5 minutes starting from loading on test items. The force measurements (Pmax) on the instant of breaking point were read and bending strength (σE) was calculated according to the formula below (Bektaş, 1997; Kasal et al., 2010).

$$\sigma_g = \frac{3.P_{max}.I}{2.b.h^2} \ (N/mm^2)$$

In this equation;
Pmax : The pressure applied at breaking point (N)
I : The space between fulcrums (mm)
b ; The width of test specimen vertical to annual rings (mm)
h ; The thickness of test specimen tangent to annual rings (mm).

When the static bending strength needed to be adjusted to a 12% moisture value, this figure was calculated using the following equation.

$$\sigma_{b12} = \sigma_g \times \left[1 + \frac{\alpha}{W - 12}\right] \ (N/mm^2)$$

In this equation;
α : 0.04 (correction factor for humidity amount)
W : the humidity amount for wood calculated in accordance with TS 2471

The Determination of Elastic Modülüs

In this step, the elastic modulus for the difference of force applied to elastic deformation area (ΔF) was calculated using the difference between deflections in samples (Δf) by means of the equation below (Bektaş, 1997).

$$E = \frac{\Delta . F . L^3}{4 . b . h^3 \Delta f} (N/mm^2)$$

In this equation;
ΔF : the force equal to the difference between the arithmetic means of the lower and upper limits of loading at the elastic deformation area (N)
L ; The space between fulcrums (mm)
Δf : The deflection in net bending area, the difference between arithmetic means of deflection results measured at the lower and upper limits of loading (mm)
b ; Section width of test item (mm)
h ; section thickness of test item (mm)

When the pressure strength needed to be adjusted to a 12% moisture value, this figure was calculated using the following equation.

$$E_{12} = E \times \left[1 + \frac{\alpha}{W - 12}\right] (N/mm^2)$$

In this equation;
α : 0.02 (correction factor for the humidity amount)
W : the humidity value for wood calculated in accordance with TS 2471

The Determination of Compression Strength Parallel to the Fibres

TS 2595 (1976) was the basis for determining compression strength parallel to the fibres. Control and test samples were prepared from wooden material of the dimensions 20x20x30 mm. Before the experiment, the cross-sectional area where the force was to be applied was measured at 0.01 mm sensitivity (axb), the maximum force at breaking point (Pmax) was determined and the compression strength was calculated by the following formula (Bektaş, 1997).

$$\sigma_{w//} = \frac{P_{MAX}}{a . b} (N/mm^2)$$

In this equation;
σ w// : Compression strength parallel to the fibres (N/mm^2)
Pmax : The maximum load (N)
a and b : Cross-sectional dimensions of the test piece (mm^2)

When the pressure strength needed to be adjusted to a 12% moisture value, this figure was calculated using the following equation.

$$\sigma_{12} = \sigma_w \times \left[1 + \frac{\alpha}{W - 12}\right] (N/mm^2)$$

In this equation;
α : 0.05 (correction factor for the moisture value)
W : the moisture value of wood calculated in terms of TS 2471

The Determination of Screw Holding Strength

TS EN 13446 was taken as the basis for determining the screw holding strength. The screw holding strength was conducted in the radial direction. Wooden materials of dimensions 50x50x20 mm were prepared from the test samples. The midpoints of the cross sections of the prepared test samples were determined and screws were inserted in such a way so that 2/3 of the 35 mm screws would enter the wood. In this study, according to the principles frequently favored in the furniture industry and specified in TS 431, screws measuring 3.5x50 mm, made from low carbon steel, with a flat countersunk head, with a star twist and helical gear, were used. The thickness of the test pieces and the depth of penetration were determined by measuring with ± 0.1 mm sensitivity according to EN 325 (Perçin and Ayan, 2012).

The Determination of Bonding Strength Parallel to Fibres

The test specimens used in the test for bonding strength parallel to fibres were bonded with a high quality PVA based and D2 norm wood adhesive, resistant to outdoor conditions. The glue used was polyvinyl acetate (PVA) based - a white glue which is a strong glue that can be used in any kind of wood and becomes transparent when it is dry. It is in D2 norm and it is resistant to medium levels of humidity. It can be diluted with water, is ideal for framing works and has excellent adhesion strength. It is used in hardwoods, MDF, chipboard and any kind of woods where the purpose is to bond it to other materials of its kind. Approximately 10 minutes of application time is needed to ensure adequate adhesion (URL-2).

TS EN 205 was taken as the basis for determining the bonding strength parallel to fibres. The test specimens were prepared from wooden materials with dimensions of 20x15x150 mm. A constant pulling force was applied, homogeneous to the cross section of prepared samples, for 1.5-2 minutes. The maximum force (F) at the moment of breaking was determined by maintaining the application of force until the sample broke. Adhesion strength (σY) was calculated as follows (Uysal and Kurt, 2005).

$$\sigma_Y = \frac{F}{A} = \frac{F}{a \times b} (N/mm^2)$$

In this equation;
σ Y : bonding strength (N/ mm^2)
F : force at the moment of breaking(N)
A : bonding area (mm^2)
b : width of bonding surface (mm)
a : the length of the bonding surface (mm)

RESULTS AND DISCUSSION

Physical Properties

An analysis from statistical information is given average values are in Table 6, an analysis of the variance from statistical information on the determination of retention and oven dry density quantities of the experimental samples is given in Table 7, the least significant difference (LSD) is in Table 8, and graphical representations of results are in Figure 3.

As shown in Table 6, the highest average retention rate of samples in an air-dried state (12%) in test samples was 194.80 kg/m^3

in samples impregnated with a 5% borax solution. It was found that the retention rate increased as the boron compound concentration increased in all impregnation processes that were carried out. In test specimens impregnated with quebracho - which is one of the natural impregnations - the density value in oven dry conditions was found to be 0.57 g/cm^3 in the impregnation with the highest 1% borax. The oven dry density value of the control samples was identified as 0.53 g/cm^3. Full dry density values of the boron compounds impregnated with boric acid solutions seemed to be lower than those impregnated with borax solutions. It was found that as the concentration of boron compound increased in the impregnation solution, the oven dry density values increased.

In Toker's (2007) study, he impregnated oriental beech woods with various concentrations of borax and boric acid. Retention rates were found out to be 4.95 kg/m^3 with 1% boric acid concentration, 13.86 kg/m^3 with 3% boric acid, 26.69 kg/m^3 with 5% boric acid, 5.03 kg/m^3 with 1% borax, 15.20 kg/m^3 with 3% borax and 25.22 kg/m^3 with 5% borax. In this study also, the concentration of the boron compound and the retention rate increase in direct proportions. The results we obtained are consistent with this study. In this study Peker et al., 1999 found the retention rate to be 10.57 kg/m^3 in samples impregnated with (borax + boric acid) by impregnating oriental beech woods with boron compounds, phosphorus compounds, ammonium compounds and organic solvents.

Table 6. Amount of some physical properties of beech wood

		Boron Compounds						
		Borax			Boric Acid			
Impregnation Materials	S.S.	1%	3%	5%	1%	3%	5%	Control
Qebracho		Retention Amount (kg/m^3)						
	M	29.00	96.33	194.80	5.39	45.96	127.56	-
	Sx	3.10	11.53	13.76	2.51	4.36	12.08	-
		Oven-Dry Density (g/cm^3)						
	M	0.57	0.56	0.55	0.53	0.55	0.56	0.53
	Sx	0.04	0.04	0.03	0.04	0.04	0.02	0.03

S.S.: Statistical Symbol, M:Mean, Sx:Standard Deviation

Table 7. Multivariate analysis of variance for the determination of the physical properties of beech wood

		Retention Amount			Oven-Dry Density			
Source of Varience	F. D.	S. S.	S. M.	F. V.	F. D.	S. S.	S. M.	F. V.
Boron Compounds	1	33244.60	33244.60	396.36*	1	0.0034	0.0034	2.67
Solution Concentration	2	211670.31	105835.16	1261.82*	2	0.0007	0.0004	0.29
bc*c	2	4840.08	2420.04	28.85*	2	0.0054	0.0027	2.15
Error	54	4529.25	83.88		54	0.0682	0.0012	
Total	59	254284.24			59	0.0777		

F.D.: Degrees of Freedom; S.S.: Sum of Squares; S.M.: Mean of Squares; F.V.: F Value; *, **: 1% and 5% significance level, respectively

Table 8. Test results of LSD with physical properties of variable of impregnating agents, boron compounds and solutions concentrations

		Retention Amount (kg/m^3)		Oven-Dry Density (g/cm^3)	
Factor	Material	[1]M	[2]LSD	M	LSD
Boron Compounds	Borax	106.71 a	4.7409	0.56 a	0.0184
	Boric Acid	59.64 b		0.54 a	
Solution Concentration	1%	17.20 [3]c	5.8064	0.54 a	0.0225
	3%	71.14 [3]b		0.55 a	
	5%	161.18 [3]a		0.55 a	

[1]M: Mean; [2]LSD: Least significant difference; [3]a,b,c: Mean grouping

In his work, Gür (2003) impregnated the samples, which were prepared from scots pine and red pine woods, with the vacuum pressure technique using Tanalith C and vacsol WR impregnation materials. After the impregnation process, the samples' specific weight were found to increase. By impregnating scots pine and oriental beech woods with certain impregnation substances, the changes that occur in oven dry and air dry densities were investigated. As a result, the air dry density of scots pine was determined to be affected most in vacsol, styrene + MMA, and isocyanate while the oven air density of scots pine was determined to be affected most by vacsol, isocyanate, paraffin + boric acid + borax and isocyanate (Örs et al., 1999). It is observed in literature that impregnated materials increase the density of wooden materials. Studies on beech species around the world indicate that (according to the density classes), air-dry density is between 0.50 – 0.69 g/cm^3 and that the beech enters the group of trees in medium density (Bozkurt and Erdin, 1990). In this study, it was determined that full dry density findings values were close to those in literature.

Figure 3. The average values of physical properties of beech wood impregnated with quebracho and boron compounds

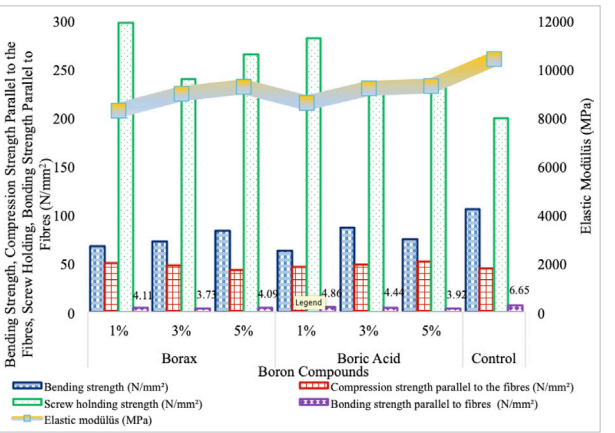

Figure 4. The average values of mechanical properties of beech wood impregnated with quebracho and boron compounds

Table 9. Amount of some mechanical properties of beech wood

Impregnation Materials	S.S.	Boron Compounds						
		Borax			Boric Acid			Control
		1%	3%	5%	1%	3%	5%	
Qebracho		Bending Strength (N/mm²)						
	M	67.40	72.80	83.20	62.60	86.70	75.10	106
	Sx	8.68	9.05	9.43	13.21	12.03	13.73	15.5
		Elastic Modulus (MPa)						
	M	8293	8968	9257	8596	9187	9283	10400
	Sx	821	913	935	1012	1183	1459	1460
		Compression Strength Parallel to the Fibers (N/mm²)						
	M	50.57	48.08	43.42	46.37	48.41	52.07	44.39
	Sx	1.66	2.93	6.09	5.59	2.30	1.97	3.74
		Screw Holding Strength Tests (N/mm²)						
	M	297.40	239.30	264.90	281.80	235.70	234.30	199.36
	Sx	40.35	37.56	11.43	19.95	27.78	50.12	16.13
		Bonding Strength Parallel to Fibers (N/mm²)						
	M	4.11	3.73	4.09	4.86	4.44	3.92	6.65
	Sx	1.32	0.95	0.57	0.91	0.56	1.16	1.95

S.S.: Statistical Symbol; M:Mean; Sx: standard deviation

As a result of the variance analysis conducted, it was determined that the oriental beech samples impregnated with quebracho and boron compounds had a 1% significance level difference between retention rate and boron compounds and solution concentration (Table 7).

As can be seen from Table 8, the highest retention amount of the physical properties in the oriental beech was found 106.71 kg/m^3 in borax among boron compounds and to be 161.18 kg/m^3 in 5% concentration among solution concentrations. The highest oven dry density amount was found 0.56 g/cm^3 in borax among boron compounds and to be 0.55 g/cm^3 in samples impregnated at 3% and 5% among solution concentrations.

In beech samples impregnated with quebracho from natural impregnation substances, it is seen that the retention rates of boron compounds impregnated with borax are higher than boric acid. It has been observed that as the concentration of the boron compounds increases in all impregnation processes, the retention rate also increases. The highest retention rates were obtained at 5% concentration. Oven dry density values were found to be higher than those of control samples without im-

Table 10. Multivariate analysis of variance for the determination of the mechanical properties of beech wood

	Bending Strength (N/mm^2)				Elastic Modulus (MPa)			
Source of Varience	F. D.	S. S.	S. M.	F. V.	F. D.	S. S.	S. M.	F. V.
Boron Compounds	1	1.67	1.67	0.01	1	484201.7	484201.7	0.24
Solution Concentration	2	2787.63	1393.82	11.48*	2	7435143.3	3717571.7	1.82
bc*c	2	1407.63	60.43	0.01*	2	198723.3	99361.7	0.05
Error	54	6559.00	121.46		54	110080990.0	2038536.9	
Total	59	10755.70			59	118199058.3		
	Compression Strength Parallel to the Fiber				Screw Holding Strength Tests (N/mm^2)			
Boron Compounds	1	38.08	38.08	1.38	1	4133.40	4133.40	0.94
Solution Concentration	2	5.51	2.75	0.10	2	29738.80	14869.40	3.39**
bc*c	2	424.78	212.39	7.68*	2	1830.00	915.00	0.21
Error	54	1492.64	27.64		54	415117.00	3843.68	
Total	59	1961.01			59	518697.70		
	Bonding Strength Parallel to Fibers							
Boron Compounds	1	2.77	2.77	1.94				
Solution Concentration	2	2.64	1.32	0.92				
bc*c	2	2.76	1.38	0.96				
Error	54	77.19	1.43					
Total	59	85.36						

F.D.: Degrees of Freedom; S.S.: Sum of Squares; S.M.: Mean of Squares; F.V.: F Value; *, **: 1% and 5% significance level; respectively

Table 11. Test results of LSD with mechanical properties of variable of impregnating agents, boron compounds and solutions concentrations

		Bending Strength (N/mm^2)		Elastic Modülüs (MPa)		Compression Strength Parallel to the Fiber (N/mm^2)		Screw Holding Strength (N/mm^2)		Bonding Strength Parallel to Fibers (N/mm^2)	
Factor	Material	X_{ort}	LSD	X_{ort}	LSD	X_{ort}	LSD	X_{ort}	LSD	X_{ort}	LSD
B. C.	Borax	74.47 a	5.71	8839 a	739.1	47.36 a	2.72	267 a	34.29	3.98 a	0.62
	Boric Acid	74.80 a		9019 a		48.95 a		251 a		4.41 a	
S. C.	1%	65.00 b	6.99	8445 a	905.2	48.47 a	3.33	290 a	41.99	4.49 a	0.76
	3%	79.15 a		9073 a		48.25 a		250 ab		4.09 a	
	5%	79.75 a		9270 a		47.75 a		238 b		4.01 a	

B. C.: Boron Compounds; S. C.: Solution Concentration; MPa: Megapascal; LSD: Least significant difference; a,b,c: Mean grouping

pregnation. The highest full dry density value was in samples impregnated with 1% borax (Figure 3).

Mechanical Properties

An analysis from statistical information is given mean values in Table 9, variance analysis related to bending strength, elastic modulus, compression strength parallel to the fibres, screw holding strength and bonding strength parallel to fibres are shown in Table 10, LSD test results in Table 11, and graphical representations in Figure 4.

In the impregnated test specimens, the bending strength in the case of air dry (12%) was found to be 86.70 N/mm^2 in samples impregnated with the highest 3% boric acid solution. In the control samples, the bending strength value in the case of air-dry (12%) was found to be 106 N/mm^2. The bending strength of the beech samples impregnated with the boron compound mixture and natural impregnation material was found to be lower than the control samples. In the impregnated test samples, the elastic modulus in the case of air dry (12%) was found to be 9283 MPa in samples impregnated with the highest 5% boric acid solution. In the control samples, the elastic modulus in the case of air dry was found to be 10400 MPa. The maximum value of the compression strength parallel to the fibres was found to be 52.07 N/mm^2 in samples impregnated with 5% boric acid. The compression strength parallel to the fibre values of the impregnated specimens were higher than the control samples. The average screw holding strength value was found to be 297.40 N/mm^2 in samples impregnated with the highest 1% borax. In all of the impregnation processes carried out, screw holding strength of the impregnated samples were higher than the control samples. In the control samples, the average screw holding strength value - in the case of air-dry (12%) - was found to be 199.36 N/mm^2. However, in the bonding strength parallel to fibres it was found to be 4.86 N/mm^2 in samples impregnated with the highest 1% boric acid. In the control samples, the average bonding strength in the case of air dry was found to be 6.65 N/mm^2. In all of the impregnated samples the bonding strength values came out lower than the control samples (Table 9).

Reductions in strength created by impregnation substances are related to their chemical structure and their fixation reactions with wood. The impregnation substances containing acidic chromium have a hydrolytic depletion reaction with wood sugars, thus forcing interaction with the cell wall materials. During this process, which is considered a fixation, metals are reduced to a less water-soluble form by oxidation of cell wall components. However, the temperature applied before impregnation and during the fixation process accelerates these hydrolytic reactions that occur in the wood, leading to increases and decreases in mechanical properties (Temiz et al., 2004).

Toker (2007) impregnated beech wood with different concentrations of borax and boric acid in his work and found that the bending strength decreases as the solution concentration increases. He found that while the average bending strength was 101 N/mm^2 in the non-impregnated control samples, it was 89.34 N/mm^2 in the specimens impregnated with borax solution and the average bending strength perpendicular to the fibres was 88 N/mm^2 in the specimens impregnated with boric acid solution. It has been reported that finding low or high values for bending strength may be due to the different materials used. In literature, studies show that the bending strength of the oriental beech wood varies between 100 and 150 N/mm^2 and the average value is around 120 N/mm^2 (Keskin and Togay, 2003). In this study, the bending strength of non-impregnated control samples was determined to be 106 N/mm^2. This value was found to be in accordance with the literature.

The elastic modulus values of beech wood in literature were found to be as follows: Fagus orientalis (Europe) 16000 MPa (Güler and Bektaş, 2000), 15700 MPa (Bozkurt et al., 2000), 13082 MPa (Malkoçoğlu, 1994) Fagus orientalis (Andirin) 12750 MPa (Güler and Bektaş, 2000), Fagus orientalis (Iran) 11820 MPa (Güler and Bektas, 2000). In this study, elastic modulus of non-impregnated control samples was determined to be 10400 MPa.

The compression strength parallel to fibres values of beech wood were determined to be 57.2 N/mm^2 (Malkoçoğlu, 1994), 60 N/mm^2 (Bozkurt et al., 2000) and 62.9 N/mm^2 (Erdinler, 1999) in different studies conducted in literature. In the control samples, the compression strength parallel to the fibres value in the case of air dry (12%) was found to be 44.39 N/mm^2 - similar to the value in literature. The findings relating to the determination of compression strength parallel to the fibres which we obtained are similar to those in the work of Keskin.

Açıkel (2007) found out that if the screw holding strength is ordered from high to low according to the impregnation substance it is as follows: boric acid, borax, immersol-aqua and that in particular boric acid, borax and a boric acid + borax mixture have a greater effect on screw holding strength than other impregnation substances. According to the test results, the impregnation process increased the screw holding strength. This may be due to the fact that the impregnation substances enter the cell wall cavity in the tree and affect the contact surface area. It is seen that the screw holding performance values of wooden materials with a high density is high in literature. In this work too, the screw holding strengths increased. The screw holding strength of the impregnated beech samples is higher than the non-impregnated control specimens and shows similarities to the studies in the literature.

Altınok and others (2009) in their study found that borax decreased the bonding strength by 15.6% in PVAc glue, 21.5% in UF glue and 37.7% in PU glue. It is seen in studies in literature that there is a decrease in bonding strength in impregnated wooden materials with pressure applied impregnation methods. Many factors influence bonding strength such as the impregnation method, the amount of retention, and the nature of the impregnation material. In his work Rowell (2005) investigated the factors that influence the bonding strength of wooden materials. As a result of the study, it was determined that many factors influence bonding strength however the most signifi-

cant factors were wood, production method, glue and place of use.

As a result of the variance analysis conducted; it was determined that there was a difference of 1% significance between the solution concentration and the boron compounds * concentration in the change in bending strength. There was a 1% significance level difference between the concentration and the boron compounds * concentration at the parallel pressure strength. A difference in 5% significance was found between screw holding strength and solution concentration (Table 10).

The highest bending strength change was obtained as 74.80 N/mm^2 in boric acid for boron compounds and as 79.75 N/mm^2 for samples impregnated at 5% concentration in terms of solution concentration. The highest elastic modulus values were obtained in specimens impregnated with boric acid at 9019 MPa in boron compounds and 5% concentration at 9270 MPa in solution concentration. The highest change in compression strength parallel to fibres was obtained in samples impregnated in 1% concentration with 48.95 N/mm^2 boric acid for boron compounds and with 48.47 N/mm^2 for solution concentration. The highest screw holding strength value was obtained in samples impregnated in 1% concentration with 267 N/mm^2 borax for boron compounds and 290 N/mm^2 for solution concentration. In the impregnated samples, the highest compression strength parallel to fibres values were obtained in 1% concentration with 4.41 N/mm^2 boric acid for boron compounds and with 4.49 N/mm^2 for solution concentration. It has been reported that finding low or high values relating to the determination of these strength values may be due to the difference in the materials used (Table 11).

As can be seen in Figure 4, the bending strength of the beech samples impregnated was found to be lower than the control samples. The average elastic modulus values were lower than the control samples and the increase in the elastic modulus values increased as the solution concentration increased. It was found that the compression strength parallel to fibres was higher than the strength control samples. In terms of solution concentration, the compression strength parallel to the fibres was determined in the boric acid samples with the highest concentration of 5%. In all of the beech samples impregnated with quebracho and boron compounds, the screw holding strength was higher than the control samples. All of the beech samples were found to have lower bonding strength than the control samples. It can be argued that this decrease is due to the fact that boron compounds negatively affect the chemical structure of the glue used, making it difficult for the glue to penetrate into the wood material, and it also adversely affects adhesion and cohesion forces between the layers (Özçifçi, 2005).

CONCLUSION

As a result of impregnations made, it was found that the retention rate of borax in boron compounds is higher than boric acid. According to this result, it can be said that borax is a better absorber than boric acid. The retention rates increased as the concentration of the boron compounds increased. The highest retention value was detected in samples impregnated with a solution of 5% concentration. This can be explained as the concentration of the boron compound increases, the amount of the substance bonding to the wood increases. As a result of the experiments, the oven dry density values of the impregnated samples were found to be higher than the control samples. This can be interpreted as the fact that the boron compounds used in the impregnation process have salt properties and thus increase the density of the wood material. The average oven dry density value was found to be higher in borax from boron compounds. It was seen that the increase in the boron compound concentration also increased the oven dry density value. It was found that the oven dry density values of the impregnated samples were higher than those of non-impregnated control samples, which is consistent with literature.

After the impregnation process, a general decrease was found in the bending strength perpendicular to the fibres. It was found that as the boron compound concentration increases, the increase in the bending strength parallel to the fibres of the test samples increases. This can be attributed to the impregnation salts in the crystal structure being placed between the micelles in the cell wall, resulting in a decrease in the bonding property of the material. The values in the elastic modulus were found to be lower than the control samples. It was found that in boron compounds values were lower than the control samples and compared to boric acid lower results were obtained from borax. As the solution concentration increased, the elastic modulus values increased. As a result of the experiments conducted, it was found that the compression strength parallel to the fibres were generally higher than the control samples. In the boron compound concentration, the highest value was found in boric acid at 5% concentration. As a result of the tests conducted, the screw holding strength was found to be higher in the impregnated samples than in the control specimens. It was found that borax in boron compounds has higher values than boric acid. As the concentration of the boron compound increased, a decrease in screw holding strength was detected. Despite this decrease, even the screw holding strength values in 5% concentration were higher than the control samples. As a result of the tests made, the bonding strength of the impregnated samples was found to be lower than the control samples. It was found that boric acid in boron compounds have higher results than borax. The highest value in boron compound concentrations was found at 1% concentration.

According to the results of the tests conducted, if we compare the boron compounds with each other, it is determined that in the samples impregnated with borax, retention, oven dry density and screw holding strength values were higher than boric acid, and elastic modulus and bonding strength parallel to fibres values were lower. If we compare the test results with the control samples, oven dry density, compression strength parallel to the fibres and screw holding strengths in the impregnated samples were higher than the control samples. Bending

strength, elastic modulus and bonding strength parallel to the fibres were lower than the control samples.

Alternative impregnation materials, which do not harm nature and humans, should be sought instead of chemical impregnation materials used in the preservation (impregnation) of wood materials, which have occupied a prominent place in the global forest products industry in recent years. In this study, some properties of wood materials were tested by applying mixtures of natural impregnation substances that are rich in boron and tannin - which have enormous potential in Turkey - to wood materials. Thus, it was aimed to increase the use of these materials in the impregnation field and thus contribute to the country's economy and the environment.

In this study, quebracho was used as a natural impregnation material, and borax and boric acid were used as chemical impregnation substances. In works to be conducted later, it may be recommended using different boron compounds with different natural impregnation materials. In addition, this blend can be compared by determining the effects on the wood material by adding other ingredients.

The objective is to increase industrial use of the application of mixtures of boron minerals to wood materials, which have a great potential in Turkey, as well as natural impregnation materials rich in tannins. It follows that this will therefore contribute to the economy of the country.

In addition, natural impregnation materials which are not harmful to nature and human beings should be used rather than chemical impregnation substances used in the preservation (impregnation) of wooden materials – substances which have occupied an important place in the global forest products in recent years.

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