The Technological Properties of Oriental Beech (*Fagus orientalis* Lipsky) Impregnated with Boron Compounds and Natural Materials

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Impregnation, drying, and varnishing are performed to increase the usage life of wood material by making it resistant to chemical, physical, and biological agents. The most common wood protection procedures are chemical methods. Therefore, it is essential to develop new impregnation substances that do not harm the environment and human health but are still economically efficient. In this study, oriental beech (*Fagus orientalis* Lipsky) was impregnated with borax and boric acid in 1%, 3%, and 5% aqueous solutions. Quechua (*Caesalpinia spinosa*) was also used as a natural impregnation substance. The retention amount of the impregnated samples was examined for the oven-dried density, bending strength, elastic modulus, screw holding strength tests, compression strength parallel to the grain, and Bending strength parallel to the grain. The samples impregnated with borax had higher oven-dried density, bending strength, elasticity modulus in bending, and Bending strength parallel to the grain tests than samples treated with boric acid; however, the screw holding strength tests showed the opposite trend. The screw holding strength was higher in the impregnated samples than in controls. The bending strength, the elasticity modulus in bending, and the Bending strength parallel to the grain were lower in the control samples.

Keywords: Oriental beech; Impregnation; Quechua; Boron compounds; Tannin

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INTRODUCTION

Wood materials are used in many different sectors, and their use has increased over time because they have easy processability, nail and screw holding features, and high strength despite their lightness (Aslan 1998).

Wood is a popular building material, but it has advantages and disadvantages compared with other building materials. Wood can be used in many areas, and it is an organic, natural, renewable raw material. Its anatomic structure, mechanical properties, physical properties, and chemical composition enable wood to be used in many different products (Baysal 1994; Hafızoğlu *et al.* 1994; Ors *et al.* 2008). Wood also has the tendency to burn and decompose. Its disadvantages include changes in size after it is exposed to moisture until it reaches the equilibrium humidity. Another disadvantage is that wood can be destroyed by insects and fungi (Budakçı 2003).

Wood maintains its importance and relevance because of its outstanding features. Wood degrades in different environmental conditions (water, sun, rain, snow, wind) and after exposure to chemical and biological agents, fungi, and insects, leading to a shorter service life. Impregnation processes with various chemical methods prevent these unfavorable situations and extend the wood usage time (Bozkurt *et al.* 1993). Untreated wood can be damaged by insects, fungus, humidity, fire, *etc*., leading to repairs, replacement, and maintenance before its economic life expires (Richardson 1987; Keskin 2003; Keskin 2009). Impregnation with boron compounds prevents biological damage (Winandy and Morell 1990).

Overall, wood materials do have many shortcomings, which include possible damage from biological agents, its ability to change size due to atmospheric humidity and application of heat, and its flammable properties that can further degrade the wood material. If one wants their wood materials to last longer, they need to be coated with protective materials or an effective impregnating method must be used (Uysal 2005).

Impregnation is a process that uses various methods to protect wood, an anisotropic substance, from biotic and abiotic factors. The elements affecting the impregnation include wood material characteristics, impregnation methods, the flow lines of the fluids, the gate aspiration, *etc*. (Bozkurt *et al.* 1993). The success of impregnation is related to properties including the amount of oven-dried impregnation material (also known as retention) that is present, the permeation depth of the impregnation itself, the impregnation material used, and the properties specific to the type of wood being used (Baysal *et al.* 2003).

The permeation depth of the impregnation into the wood and the possible differences in the concentrations of remaining protecting agent is as important as the chemicals used during the impregnation process. The usage life of wood material changes as to the penetration depth changes. Its drawbacks include the possible decomposition of wood materials by insects and fungus, its change in size depending on the humidity, flammability, and its overall possibility of deformation. Therefore, these properties limit the usage life. For this reason, it is suggested that wood can be used for a rather long time if it is impregnated with protective chemical substances (Yalınkılıç *et al.* 1995).

Boron compounds are currently accepted as some of the safest chemicals used as a protective impregnation material. Boron compounds have gained importance gradually while still having a minimum negative effect on humans and the environment. They are seen as being the most important impregnation material of the future because they feature less toxic properties than the impregnation materials used containing heavy metal. Besides the properties that are directed against fungus and termites, boron compounds increase the fire resistance of wood, which extends the usage areas of boron compounds (Lloyd 1998).

Tannins are amorphous substances and are also known as tannic acid. Their colors range from light straw to dark reddish brown. They are found in high-build plants such as chestnut, oak, oak, and sumac. They are water-soluble polyphenolic compounds with a high degree of chemical structure and a molecular weight of up to 20,000 Daltons. They can be found in shells, roots, leaves, fruits, and seed parts of plants. They exhibit visual characteristics ranging from light yellow to white (Khanbabaee and Ree 2001).

There is a preference for boron compounds in the wood protection because they rapidly carbonize when strongly heated, consequently emitting the water into outer layers. When the wood material encounters high temperatures, the boron compounds prevents combustion and heat leakage, resists against fungus, insects, and heat conducted inside the outer layer and the carbonized outer layer, further decreasing the loss of life and property, and the need for expensive practices. It is a popular method used because of its quick penetration into fresh lumber, its availability, abundance, and relatively low cost in Turkey. Turkey is becoming more eco-friendly because the compounds no longer contain poisonous acidic and basic compounds filled with arsenic, fluorine, and the ability for diffusion. Due to its solubility in water and humidity, it clogs the destruction through insertion into the holes which are drilled in treated or uncured wood constructions in salt lick shapes and through diffusing into the material by dissolving with the effects of water and humidity (Hafızoğlu *et al.* 1994).

Beech wood is widely preferred for use in various environments. Because of this, in this study, changes in the physical and mechanical properties of oriental beech (*Fagus orientalis* Lipsky) were examined after impregnating the wood with natural substances containing tannins and boron compounds.

Treatment of wood with glue/wax water-repellent formulations significantly increases the dimensional stability of specimens exposed to wet conditions and greatly decreases the proportion of water flow in the capillaries (Lesar and Humar 2011). The use of preservative-impregnated wood or the availability of termite-resistant tropical heartwoods occurs more and more restricted. Bid fairing attitude includes the use of thermally or chemically modified wood (Nemeth *et al.* 2015; Scholz *et al.* 2010).

EXPERIMENTAL

Materials

Oriental beech was cultivated at an altitude of approximately 1200 m in Alacadağ, Kürtün District, Gümüşhane Province. The test samples were prepared from the defect-free parts of the wood by paying attention to the fiber directions of the wood; the wood was dried to an appropriate moisture gradient.

Quechua, which contains hydrolysis tannin, was used as the natural impregnation material. Tara is a small tree that is native to north and west South America. It grows best in very tropical and warm temperate climate. Quechua extract has a dark brown color and consists of 60% tannins (Fig. 1).

Its pH value is about 3.5. It is hydrolyzed tannin. Its extracts have similar characteristics like sumac and Turkish gallnut tannins that are used in tannery and paint protection (URL-1 2015).

Used glue is polyvinyl acetate (PVA). It is a white glue based on a strong glue which can be used in any kind of wood which becomes transparent when it is dry. It is D2 norm which is resistant to moisture in the moderate. It can be diluted with water. It is ideal for skeleton work and has excellent adhesion strength. It is used in hardwoods, MDF, chipboard and any kind of wood, with the purpose of sticking to any other material of its kind. Approximately 10 min of application time is needed to ensure adequate adhesion (URL-2).

For the impregnation process, the solution was first prepared by using tara tannins. Solution was prepared by dissolving in water using 5% mineral tannin materials based on the amount of weight. The aqueous solutions of boric acid or borax were used in 1, 3, and 5% concentrations. The mixtures of natural impregnation material and boron compounds were used in impregnation procedure.

The boron compounds were provided from the Eti General Directorate of Mining Enterprises.

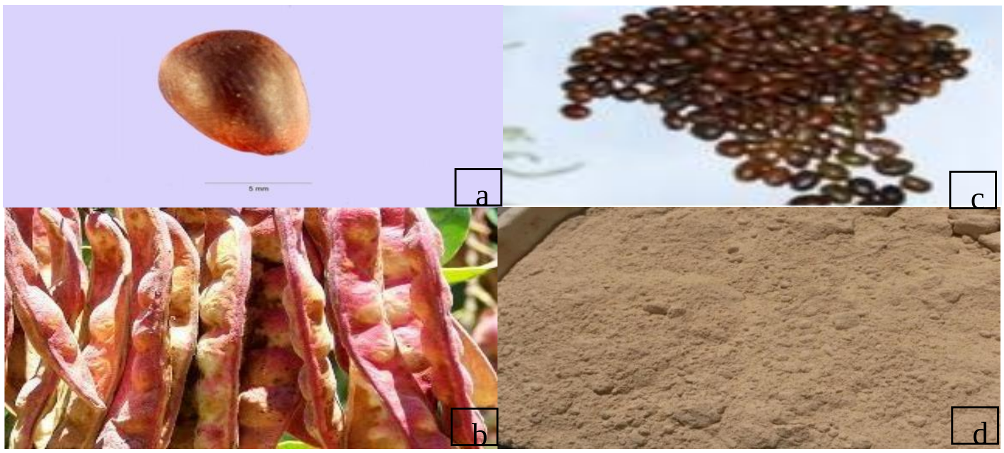

Fig. 1. Seed (a), fruit (b), extract (c), and wood (d) of Quechua

Methods

Liquefaction of the biomass

Oriental beech (*Fagus orientalis* Lipsky) samples were prepared in sizes according to the Turkish Standards Institution (Table 1). A total of 420 samples were prepared including 10 control samples for each test. The retention and oven-dried density of the samples were calculated from their oven-dried weight and confirmed by fractionally raising the heat from 65 °C to 105 °C until their weights became stable.

Table 1. Standard and Size Samples in the Physical and Mechanical Properties of Beech Wood

Properties	Test	Sample Size (mm)	Standard
Physical	Retention	20 x 20 x 30	ASTM D 1413-07 (2007)
	Oven Dried Density	20 x 20 x 30	TS 2472 (1976)
Mechanical	Bending Strength	20 x 20 x 360	TS 2474 (1976)
	Elastic Modulus	20 x 20 x 360	TS 2474 (1976)
	Compression Strength Parallel to Grain	20 x 20 x 30	TS 2595 (1976)
	Screw Holding Strength	50 x 50 x 20	TS EN 13446 (2005)
	Bending Strength Parallel to Grain	20 x 15 x 150	TS EN 205 (2004)

A total of six separate impregnation processes were completed. The full cell method was chosen in accordance with ASTM D 1413 (2007). The samples were subjected to a preliminary vacuum for 30 min and then 10 bars pressure for 30 min.

The impregnated samples were stored at 20 ± 2 °C and 65% relative humidity rate for a week, such that the wood reached 12% equilibrium humidity. To determine the retention and oven-dried density, samples were converted again into the oven-dried state after the impregnation, and the necessary measurements are performed before the physical and mechanical tests.

The wood sizes used to determine the physical and mechanical properties and the testing standards are listed in Table 1.

Determining the physical and mechanical properties of beech wood measured in triplicate were used to conduct an analysis of variance employing randomized block factorial experimental design using SAS software. The mean values were compared using the least significant difference test. In the end, multiple correlation analysis was performed in order to examine the connections between groups.

RESULTS AND DISCUSSION

The variance analysis of the retention, oven-dried density, bending strength, elastic modulus, compression parallel to grain, screw holding strength, and bending strength parallel to grain values of the test samples is in Table 2. The least significant difference (LSD) is shown in Fig. 3, and the average values are shown in Table 4. Figure 2 shows the graphical display of results.

The variance analysis showed that the physical properties had a 1% change in the significance level between the retention quantity of oriental beech samples (impregnated with quechua and boron compounds), boron compounds, solution concentration, and boron compounds concentrations (Table 2).

Table 2. A Multi-Variate Analysis of the Variance for Determining the Physical and Mechanical Properties of Beech Wood

Source of Variance	F. D.	S. S.	S. M.	F. D.	F.D.	S. S.	S. M.	F. D.
Physical Properties								
	Retention				Oven-dried Density			
Boron compounds	1	5252.5	5252.5	33.53*	1	0.0031	0.0031	2.72
Solution concentration	2	31756.4	15878.2	101.36*	2	0.0025	0.0012	1.09
bc*sc	2	1944.7	972.4	6.21*	2	0.0017	0.0009	0.75
Error	54	8459.3	156.7		54	0.0613	0.0011	
Total	59	47413.0			59	0.0685		
Mechanical Properties								
	Bending Strength				Elastic Modulus			
Boron compounds	1	721.1	721.1	4.94**	1	15150375	15150375	7.66*
Solution concentration	2	145.9	73.0	0.50	2	1073503	536752	0.27
bc*sc	2	2905.6	1452.8	9.95*	2	5933410	2966705	1.50
Error	54	7884.0	146.0		54	106797730	1977736	
Total	59	11656.6			59	128955018		

		Compression Strength Parallel to Grain				Bending Strength Parallel to Grain		
Boron compounds	1	313.7	313.7	8.59*	1	1.58	1.58	0.57
Solution concentration	2	1193.2	596.6	16.33*	2	4.40	2.20	0.80
bc*sc	2	394.3	19.1	5.40*	2	17.62	8.81	3.18**
Error	54	1972.5	36.5		54	149.46	2.77	
Total	59	3873.7			59	173.06		
	Screw Holding Strength							
Boron compounds	1	1008.6	1008.6	0.31				
Solution concentration	2	57408.1	28704.1	8.70*				
bc*sc	2	4923.1	2461.6	0.75				
Error	54	178239.8	3300.7					
Total	59	241579.6						

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

The mechanical properties showed a 5% change in the boron compounds, a 1% change in the significance level of boron compound concentrations in the bending strength, and a 1% change in the significance level between boron compounds and elasticity modulus. The compression parallel to grain had a 1% change in the significance level between boron compounds, boron compound concentrations, and the solution concentration. In the Bending strength parallel to the grain, there was a 5% change in the significance level between the Bending strength parallel to the grain and the boron compound concentration. There was a 1% change in the significance level between the screw holding strength and the solution concentration (Table 2).

As shown in Table 3, the highest retention value in physical properties of Oriental beech measured in boron compounds was 44.42 kg/m³ in borax, while it was 66.46 kg/m³ in samples with 5% concentration. The highest value for oven-dried density was identified in boron compounds as 0.54 g/cm³ in borax and was observed for the solution concentrations of 0.54 g/cm³ in samples impregnated with 5% concentration.

The highest bending strength was obtained with the borax at 80.77 N/mm² with respect to the boron compounds, whereas it was obtained as 78.80 N/mm² in the samples impregnated at 1% concentration in terms of the solution concentration. The highest value of elasticity modulus was obtained as 9560 MPa in borax, and in boron compounds impregnated with 5% concentration in the solution concentration it was obtained as 9245 MPa. The highest compression value parallel to the grain change in terms of boron compounds was in boric acid with 47.94 N/mm², and the solution concentration with samples impregnated in 3% concentration was 51.94 N/mm². The highest bending compression parallel to the grain value with impregnated samples with boron compounds was 5.09 N/mm², while with borax was 5.27 N/mm² in samples impregnated with 3% concentration in the solution concentration. The highest screw holding strength value was obtained at 267 N/mm², while with the boron compounds it was obtained at 299 N/mm² in samples impregnated with 1% concentration in regard to the solution concentration (Table 3).

Table 3. Test Results for the Least Significant Difference (LSD) Between the Physical and Mechanical Properties of the Boron Compounds and Solution Concentrations

Factor	Material	Physical Properties				Mechanical Properties									
		R. (kg/m³)		O.D.D. (g/cm³)		B.S. (N/mm²)		E.M. (MPa)		C.S.P.G. (N/mm²)		B.S.P.G. (N/mm²)		S.H.S. (N/mm²)	
		Mean	LSD	Mean	LSD	Mean	LSD	Mean	LSD	Mean	LSD	Mean	LSD	Mean	LSD
B.C.	Boric acid	25.71 b	6.48	0.52 a	0.02	73.83 b	6.26	8555 b	728.0	47.94 a	3.13	4.76 a	0.86	275.30 a	29.74
	Borax	44.42 a		0.54 a		80.77 a		9560 a		43.36 b		5.09 a		267.10 a	
S.C.	% 1	11.99 c	7.94	0.52 a	0.02	78.80 a	7.66	8941 a	891.6	42.11 b	3.83	4.61 a	1.05	299.45a	36.43
	% 3	26.74 b		0.53 a		75.15 a		8988 a		51.94 a		5.27 a		286.00a	
	% 5	66.46 a		0.54 a		77.95 a		9245 a		42.90 b		4.09 a		228.15b	

B.C.: Boron Compounds, S.C.: Solution Concentration, R.: Amount of Retention, O.D.D.: Amount of Oven-dried Density, B.S.: Amount of Bending Strength, E.M.: Amount of Elastic Modulus, C.S.P.G.: Amount of Compression Strength Parallel to Grain, B.S.P.G.: Amount of Bending Strength Parallel to Grain, S.H.R.: Amount of Screw Holding Strength

Table 4 shows that the highest average retention value of an air-dried sample impregnated with 5% borax solution was 73.10 kg/m³. In all of the impregnation procedures, when the boron compound concentration values increased, the retention values did as well. In the test samples impregnated with quechua, the density value of the oven-dried state was highest at 0.54 g/cm³ in the impregnation sample which consisted of 1, 3, and 5% borax and 5% boric acid concentration. In the control samples, the intensity value in the oven-dried state was obtained at a value of 0.53 g/cm³. Thus, the oven-dried intensity values of the boron compound samples impregnated with boric acid solutions was lower than those impregnated with borax solution. Peker *et al*. (1999) determined that by impregnating Oriental beech woods with boron compounds, phosphorous compounds, ammonium compounds, and the organic solvent, the retention number of samples impregnated with (borax + boric acid) was measured at 10.57 kg/m³. Toker (2007) impregnated Oriental beech wood with borax and boric acid in various concentrations. This work reported that the retention rate for the boric acid with a concentration of 1% was 4.95 kg/m³, 3% concentration of boric acid was 13.86 kg/m³, 5% concentration of boric acid was 26.69 kg/m³, 1% concentration of boric acid was 5.03 kg/m³, 3% concentration of boric acid was 15.20 kg/m³, and 5% borax was 25.22 kg/m³. In the present study, the compounds increased at the same proportion that the retention amount did. The results reported in the present study are compatible with the previous reports.

Toker (2007) found that the average oven-dried density after impregnating the beech wood with borax was 0.65 g/cm^3, while after the boric acid was impregnated the average was 0.64 g/cm^3. In the same study, the oven-dried density of the control samples that were not impregnated was 0.49 g/cm³. Thus, after impregnation there was an increase in the oven-dried density. The intensity for different types of beech have been reported as follows: *Fagus orientalis* (Tokat), 0.589 g/cm^3; *Fagus orientalis* (Iran), 0.632 g/cm^3; *Fagus orientalis* (Sinop), 0.633 g/cm^3; *Fagus orientalis* (Andırın), 0.637 g/cm^3; *Fagus orientalis* (Black Sea), 0.640 g/cm^3; and *Fagus orientalis* (Europe), 0.669 g/cm^3 (Güler and Bektaş 2000). In the present study, the oven-dried density findings were close to the literature values. The high or low values in the oven-dried density was due to the materials being different.

The bending strength of the impregnated test samples with a 3% borax solution concentration was 88.40 N/mm² in an air-dried state. The bending strength value in the air-dried state was found as 106 N/mm² in the control samples. The bending strength of the beech samples were found to be lower than the control samples. The elastic modulus value in the impregnated test samples with 3% borax solution was highest at 9935 MPa. In the control samples, the elastic modulus in an air dried state was found to be 10400 MPa. The compression strength value parallel to the grain was found to be highest at 55.35 N/mm² in the samples impregnated with 3% boric acid. The compression parallel to grain values was high in control samples. The bending strength parallel to grain value was highest at 5.61 N/mm² in samples impregnated with 3% boric acid. The average bending strength in the air-dried state was 6.65 N/mm² in the control samples. The bending strength values in all of the samples that were impregnated were significantly lower than the control samples. The average screw holding strength value was highest at 307.90 N/mm² in the samples impregnated with 1% borax. In all of the impregnation processes performed, the screw holding strength values were higher than in the control samples. In the control samples, the average screw holding strength value was measured at 199.36 N/mm² in a air-dried state (Table 4).

Toker (2007) studied beech wood with different concentrations of borax and boric acid and reported that the bending strength declined when there was an increase in the solution concentration. However, the average bending strength of the control samples was 101 N/mm², the average of the borax solution was 89.34 N/mm², and the average bending strength parallel to grain in samples impregnated with a boric acid solution was found to be 88 N/mm². Results that were low or high on bending strength seemed to stem from different materials usage. The static bending strength value of beech wood has been reported as follows: *Fagus orientalis* (Sinop), 87.00 N/mm² (Güler and Bektaş 2000), 96.04 N/mm² (Erdinler 1999), 112.30 N/mm² (Malkoçoğlu 1994), and 120.00 N/mm² (Bozkurt *et al*. 2000); *Fagus orientalis* (Andirin), 120.10 N/mm²; *Fagus orientalis* (Tokat), 105.20 N/mm²; and *Fagus orientalis* (Europe), 123.00 N/mm² (Güler and Bektaş 2000). In the literature, the bending strength of the beech wood varies between 100 and 150 N/mm², although the average value is approximately 120 N/mm² (Keskin and Togay 2003). In this study, the bending strength of the control samples was 106 N/mm², which was consistent with the literature.

Özkan (2012) found that the average elastic modulus value of the beech wood is 14111 MPa. The elastic modulus of the control samples was 10400 MPa.

The elastic modulus values of wood beech used in different studies were: *Fagus orientalis* (Europe) 16000 MPa (Güler and Bektaş 2000), 15700 MPa (Bozkurt *et al.* 2000), 13082 MPa (Malkoçoğlu 1994), and 11621 MPa (Erdinler, 1999); *Fagus orientalis* (Andirin), 12750 MPa (Güler and Bektaş 2000); and *Fagus orientalis* (Iran), 11820 MPa (Güler and Bektaş 2000). In this study, the elastic modulus of the control samples was 10400 MPa.

Özkan (2012) showed that the average compression value parallel to grain of beech species is 48.41 N/mm². In the control samples, the compression strength value parallel to grain in an air dried state, at 12%, was 44.39 N/mm². There was an increase of 6.01% in the compression strength parallel to grain and glue line. In various studies, the compression strength values parallel to grain were 57.2 N/mm² (Malkoçoğlu 1994), 60 N/mm² (Bozkurt *et al.* 2000), and 62.9 N/mm² (Erdinler 1999). In the control samples, the compression strength values parallel to grain in an the air dried state of 12% were 44.39 N/mm². The results, which are similar to the findings in other literature, are concluded with regard to determining the compression strength parallel to the grain.

Açıkel (2007) studied the screw holding strength of different impregnation materials from highest to lowest depending on their strength. The highest impregnation material was boric acid, borax and imersol-aqua acid, as well as borax and boric acid solutions. The borax and boric acid solutions had more of an effect on the screw holding strength than other impregnation materials. According to the test results, this particular impregnation procedure increases the screw holding strength. The impregnation materials penetrate the cell wall gap, effecting the contact surface area. High-density wood materials also have a high performance in screw holding strength. This situation was confirmed in the present study. After impregnation, the density of the beech samples and the screw holding strength increased. This study was similar to others described in the literature in that the screw holding strength of the impregnated beech samples were higher than the control samples that were not impregnated.

Altınok *et al*. (2009) showed a 15.6% decrease in the bending strength of borax glue when using polyvinyl acetate (PVA) glue, a 21.5% decrease when using ureaformaldehyde (UF) glue, and a 37.7% decrease when using polyurethane (PU) glue.

Wood materials that use impregnation methods involving pressurization were observed to decrease in Bending strength. The Bending strength was affected by various factors such as the impregnation method, the retention amount, and the structure of impregnation material. Rowell conducted a study in 2005 that investigated the factors affecting the Bending strength of different wood materials. At the end of the study, many factors influenced the Bending strength, but the most important were the factors caused by wood, production methods, glue preferences, and usage area.

In the beech samples impregnated with quechua, the retention amount of samples impregnated with borax was observed to be higher than boric acid. In all of the impregnation procedures, increasing the concentration of boron compounds resulted in an increase in the overall retention amount. The highest retention values were obtained at 5% concentration. Oven-dried density values were found to be higher in control samples that were not impregnated. The highest oven-dried density value was found in the samples that were impregnated with 1, 3, 5% borax, and 5% boric acid (Fig. 2).

Table 4. Physical and Mechanical Properties of Beech Wood

Material of Impregnation	S.S.	Boron Compounds						Control
		Boric Acid			Borax			
		1%	3%	5%	1%	3%	5%	
Quechua	**Physical Properties**							
	Retention (kg/m³)							
	x	7.83	9.46	59.83	16.14	44.02	73.10	-
	S.D.	±3.10	±11.53	±13.76	±1.80	±6.80	±14.57	-
	Oven-dried Density (g/cm³)							
	x	0.51	0.53	0.54	0.54	0.54	0.54	0.53
	S.D.	±0.03	±0.03	±0.03	±0.03	±0.04	±0.03	±0.03
	Mechanical Properties							
	Bending Strength (N/mm²)							
	x	79.30	61.90	80.30	78.30	88.40	75.60	106
	S.D.	±12.08	±11.87	±9.25	±19.68	±9.06	±5.85	±15.5
	Elastic Modulus (N/mm²)							
	x	8648	8041	8977	9233	9935	9513	10400
	S.D.	±1277	±1221	±1134	±2407	±1031	±778	±1460
	Compression Strength Parallel to Grain (N/mm²)							
	x	40.85	55.35	47.61	43.37	48.53	38.19	44.39
	S.D.	± 4.49	±5.27	±7.57	±6.27	±6.65	±5.52	±3.74
	Bending Strength Parallel to Grain (N/mm²)							
	x	3.70	5.61	4.98	5.52	4.93	4.82	6.65
	S.D.	±1.88	±1.88	±1.44	±1.52	±1.60	±1.63	±1.95
	Screw Holding Strength (N/mm²)							
	x	291.00	298.60	236.30	307.90	273.40	220.00	199.36
	S.D.	±62.20	±48.	±45.63	±70.79	±64.69	±48.00	±16.13

S.S.: Statistics of Symbol, x: Mean, S.D.: Standard Deviation

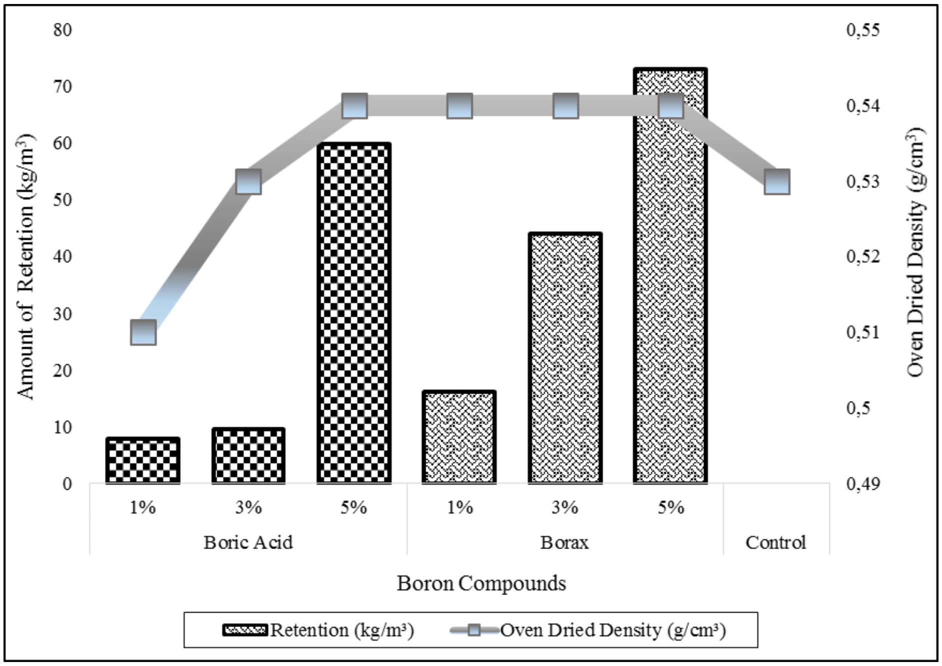

Fig. 2. The average values of the physical properties of beech wood impregnated with quechua and boron compounds

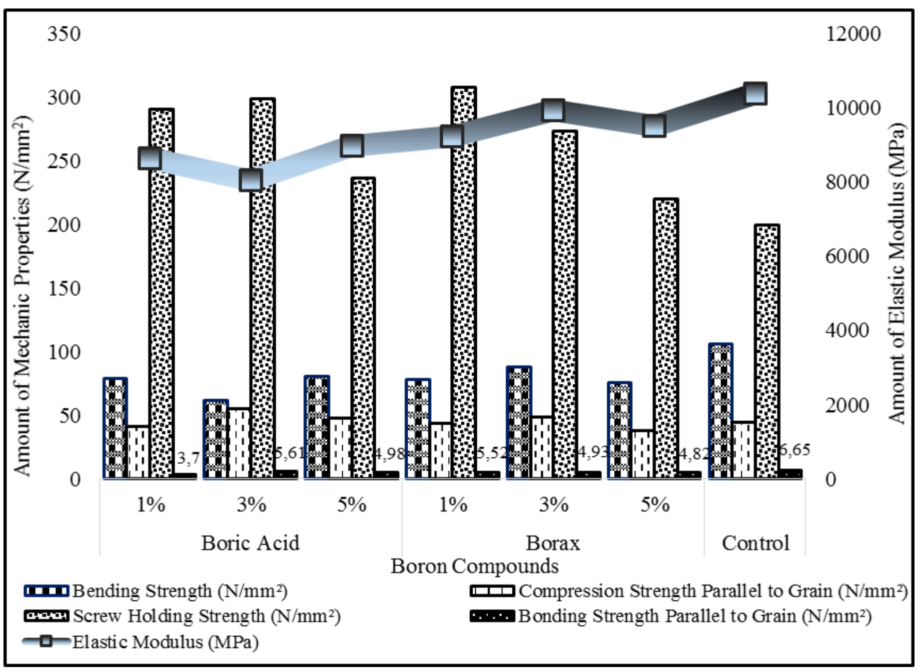

Fig. 3. The average values of the mechanical properties of beech wood impregnated with quechua and boron compounds

As shown in Fig. 3, the bending strength of the impregnated beech samples was found to be lower than the control samples. The average elastic modulus values were lower than the control samples. The compression parallel to grain was determined to be highest in samples with 3% concentration of the solution concentration. In the quechua and beech samples impregnated with boron compounds, the screw holding strength was higher than the control samples. In all beech samples, the Bending strength was lower than the control samples. This decline stemmed from the negative influences of the boron compounds and their effects on the chemical structure of the glue used. The boron compounds could not penetrate inside the wood, and this negatively affected the adhesion and cohesion force between the layers (Özçifçi 2005).

CONCLUSIONS

1. After impregnation, there was a decrease in the vertical bending to grain strength. Crystalline impregnation salts caused a decline in the cohesion of the material by settling between the micelles in the cell walls. The values in elastic modulus were lower than the control samples. The elastic modulus was lower in the control samples than in the boron compounds, while the borax had a higher result than the boric acid. After the experiments were performed, the compression strength parallel to the grain was higher than the control samples. The highest levels of boron compound concentrations were found in samples with 3% boric acid concentration levels. The Bending strength of the impregnated samples was lower than the control samples. In the screw holding strength tests, the impregnated samples had higher values than the control samples.
2. Comparing boron compounds impregnated with higher levels of borax than boric acid, the retention rate, oven-dried density, bending strength, and the elastic modulus were higher, while the compression strength parallel to the grain and screw holding strength values were lower. The screw holding strength was higher in the impregnated samples than in the control samples. The Bending strength, elastic modulus, and Bending strength parallel were lower than the corresponding values for the control samples.
3. Chemical impregnation methods are used to protect wood, but new alternatives of impregnation materials should be explored that do no harm the environment and human health. Natural materials rich in tannins and boron minerals have great potential as alternatives.

ACKNOWLEDGMENTS

This article was derived from part of a Master's Thesis from Hakan Adanur between the dates of 2012-2015. The thesis was prepared under the supervision of assistant professor Dr. Muhammed Said Fidan at Gumushane University Institute of Science and Technology in the Department of Forestry and Environmental Sciences.

REFERENCES CITED

Açıkel, I. (2007). *Effect of Screw Retention Strength in Wood Materials of Impregnation Process*, Master's Thesis, Institute of Science and Technology, Gazi University, Ankara, Turkey.

Adanur, H. (2015). *Determination of Physical and Mechanical Properties Impregnating with Some Tannins and Boron Compounds of East Beech (Fagus orientalis* Lipsky*) Wood*, Master's Thesis, Institute of Science and Technology, Gümüşhane University, Gümüşhane, Turkey.

Altınok, M., Özalp, M., Karaaslan, A., and Perçin, O. (2009). "Effects of glues modified with borax on the bending strength of chestnut wood (*Castenea sativa* Mill.)," *Journal of Bartın Forestry Faculty* 11(15), 17-24.

Aslan, S. (1998). *Tree Pests, Protection and Impregnation Technique*, Publication of KOSGEB, Ankara, Turkey.

ASTM-D 1413 (2007). "Standard test method of testing wood preservatives by laboratory soilblock cultures," ASTM International, West Conshohocken, USA.

Baysal, E. (1994). *Effect of Some Physical Properties of Wood Calabrian pine of Several Boron and WR Composite*, Master's Thesis, Institute of Science and Technology, Karadeniz Technical University, Trabzon, Turkey.

Baysal, E., Yalınkılıç M. K., Çolak, M., and Göktaş, O. (2003). "Combustion properties of calabrian pine (*Pinus brutia* Ten.) wood treated with vegetable tanning extracts and boron compunds," *Turkish Journal of Forestry* 27(4), 245-252.

Bozkurt, A. Y., Göker, Y., and Erdin, N. (1993). *Impregnate Technique*, İstanbul University Press, İstanbul, Turkey, pp. 106-107.

Bozkurt, A. Y., Göker, Y., and Erdin, N. (2000). *Anatomy of Wood*, İstanbul University, Publication Faculty of Forestry, İstanbul, pp. 117-120.

Budakçı, M. (2003). *Design and Production of a Pneumatic Adhesion Testing Device*, Ph.D. Dissertation, Gazi University, Ankara, Turkey.

Erdinler, S. (1999). "Türkish furniture foreign trade," in: *International Furniture Congress and Exhibit*, İstanbul, Turkey, pp. 19-29.

Güler, C., and Bektaş, İ. (2000). "The relationship between elasticity properties (modulus of elasticity and static bending strength) and density of eastern beech wood naturally grown in andırın," *Kahramanmaraş Sütçü İmam University Journal of Science and Engineering* 3(2), 51-57.

Hafızoğlu, H., Yalınkılıç, M. K., Yıldız, Ü. C., Baysal, E., Peker, H., and Demirci, Z. (1994). "Evaluation in wood protection (impregnation) industry of boron source in Turkey," Project Number: TÜBİTAK TOVAG- 87, 377.

Keskin, H. (2003). "Physical and mechanical properties of laminated oriental spruce wood materials," *Süleyman Demirel University Journal of Forestry* 1, 139-151.

Keskin, H., and Togay, A. (2003). "Physical and mechanical properties of laminated wood materials made op with the combination of oriental beech wood and poplar wood," *Süleyman Demirel University Journal of Forestry* 2, 101-114.

Keskin, H. (2009). "Impact of ımpregnation chemical on the bending strength of solid and laminated wood materials," *Materials and Design* 30(3), 796-803.

Khanbabaee, K., and Ree, T. (2001). "Tanens: Classification and definition," *Nat. Prod. Rep*., 18, 641-649.

Lesar, B., and Humar, M. (2011). "Use of wax emulsions for improvement of wood durability and sorption properties," *European Journal of Wood and Wood Products* 69(2), 231-238, DOI: 10.1007/s00107-010-0425-y.

Lloyd, J. D. (1998). "Borates and their biological applications," in: *The International Research Group on Wood Preservation 29th Annual Meeting (IRG/WP/98-30178)*, Maastricht, Netherlands.

Malkoçoğlu, A. (1994). *Properties Technology of Oriental beech (Fagus orientalis* Lipsky*)*, Ph.D. Dissertation, Institute of Science and Technology, Karadeniz Teknik University Trabzon, Turkey.

Nemeth, R., Tsalagkas, D., and Bak, M. (2015). "Effect of soil contact on the modulus of elasticity of beeswax-impregnated wood," *Bioresources* 10(1), 1574-1586. DOI: 10.15376/biores.10.1.1574-1586.

Ors, Y., and Keskin, H. (2008). *Technology of Wood Materials*, Textbook, Gazi University, P. No: 352, Gazi Publication Company, Ankara, Turkey.

Ozçifçi, A. (2005). "Lecture: Wood glues," Z.K.Ü. Faculty of Karabük Technical Education, Karabük University, Karabük, Turkey.

Özkan, S. (2012). *Investigation of Bending Properties of Beech Wood (Fagus orientalis* L.*) Using Nondestructive Method*, Master's Thesis, Institute of Science and Technology, Süleyman Demirel University, Isparta, Turkey.

Peker, H., Sivrikaya, H., Baysal, E., and Yalınkılıç. (1999). "Static bending strength of wood treated with fire reterdant and water repellent preservation chemicals," *Pamukkale University Journal of Engineering Science* 5(1), 975-982.

Richardson, B. A. (1987). *Wood Preservation*, Routledge, London, UK.

Rowell, R. M. (2005). *Handbook of Wood Chemistry and Wood Composites*, CRC Press, Boca Raton, FL, USA.

Scholz, G., Militz, H., Gascón-Garrido, P., Ibiza-Palacios, M. S., Oliver-Villanueva, J. V., Peters, B. C., and Fitzgerald, C. J. (2010). "Improved termite resistance of wood by wax impregnation," *International Biodeterioration & Biodegradation* 64(8), 688-693. DOI: 10.1016/j.ibiod.2010.05.012.

Toker, H. (2007). *Determination of Effects of Boron Compounds on Some Physical Mechanical and Biological Properties of Wood*, Ph.D. Dissertation, Institute of Science and Technology, Gazi University, Ankara, Turkey.

TS 2472 (1976). "Determination of specific gravity for physical and mechanical Testing in wood," Turkish Standards Institution, Ankara, Turkey.

TS 2474 (1976). "Determination of the static bending strength of wood," Turkish Standards Institution, Ankara, Turkey.

TS EN 13446 (2005). "Wood-based panels – determination of withdrawal capacity of fasteners," Turkish Standards Institution, Ankara, Turkey.

TS EN 205 (2004). "Bendings-overlap shear strength of the annexes with cut-glued determination of wood adhesives for non-structural applications," Turkish Standards Institution, Ankara, Turkey.

TS 2595 (1976). "Compression strength parallel to grain of wood," Turkish Standards Institution, Ankara, Turkey.

URL-1 (2015). "Vegetable tanning", (http://tr.scribd.com/doc/27007581/bitkiseltabaklama#scribd), Accessed 15 March 2015.

URL-2 (2015). "Bending", (http://www.asmmarketing.com/PolidolKatalog.pdf), Accessed 15 March 2015).

Uysal, B. (2005). "Lecture notes: Wood material," Z.K.Ü. Faculty of Karabük Technical Education, Karabük University, Karabük, Turkey.

Winandy, J. E., and Morell, J. J. (1990). "Protection of wood design in adverse environments," *Proceedings of I. Forest Product Journal* 354-359.

Yalınkılıç, M. K., Baysal, E., and Demirci, Z. (1995). "Effects of some boron compounds and/or water repellents on the higroscopicity of brutia pine (*Pinus brutia* Ten.) wood," *Pamukkale University Journal of Engineering Science* 1(2-3), 161-168.

Article submitted: November 1, 2016; Peer review completed: January 7, 2017; Revised version received and accepted: January 8, 2017; Published: January 17, 2017.
DOI: 10.15376/biores.12.1.1647-1661