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Screw Withdrawal Strength Some Impregnated Wood Materials

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Abstract: This study was carried out to determine the effect of the impregnation process on screw withdrawal strength in some wood materials. In this regard, the samples prepared from the woods are most commonly used in the furniture industry such as Oriental beech (*Fagus orientalis lipsky*) (I), European oak (*Quercus petreae lipsky*) (II) and Scotch pine (*Pinus sylvestris lipsky*) (III) were impregnated with borax (Bx), boric acid (Ba), borax+boric acid (Ba+Bx), Imersol-aqua (Ia) and Timbercare-aqua (Ta) in accordance with ASTM D 1413, TS 344 and TS 345. The screws 3.5×50 mm (S_1) and 4×50 mm (S_2) that were connected to the cross surfaces of the impregnated samples were subjected to withdrawal test in accordance with TS EN 13446. As a result, the highest screw withdrawal strength was obtained in European oak (3.675 N mm^{-2}) and the lowest in Scotch pine (2.693 N mm^{-2}) for the wood type. The highest screw withdrawal strength was obtained in S_2 (3.363 N mm^{-2}) and the lowest in S_1 (3.222 N mm^{-2}) in for the screw diameter. The highest screw withdrawal strength was obtained in II + Bx + S_1(4.193 N mm^{-2}) and the lowest in III + Ba + S_1 (2.251 N mm^{-2}) for the interaction of wood type, impregnation material and screw diameter. So, the impregnation process increased the screw withdrawal strength. It can be said that, in the applications, where the pieces are impregnated with Bx and connected with V_1 at the cross surface shall display the highest strength.

Key words: Boron compounds, screw withdrawal strength, Imersol-aqua, impregnation, Timbercare-aqua

INTRODUCTION

The wood material maintains its significance in many fields of use today due to its superior features. The wood material wears out as dependent on the environmental conditions such as water, sun beams, rain and snow. Wood components disrupt by means of the chemical or biological factors (Atar, 2008). In many fields of use, it is rot by the mushrooms and its economic life is shortened by the harmful effects of the insects (Evans *et al*., 1992). In order to remove these disadvantages and to extend its economic life, it is impregnated by means of various chemical materials and methods (Higley and Kink, 1990).

In making the wood goods, the screws that are the mechanical connection components providing more practical and easier connection are recently used as well as the various traditional connections. The rigidity of the wood goods is substantially dependent on the screws and the screw withdrawal capabilities of the wood materials used in their production. For this reason, the determination of the screw withdrawal strengths of the impregnated wood materials is essential for both the manufacturer and the consumers due to safety reasons.

The highest screw withdrawal strength was obtained in Oriental beech; the lowest screw withdrawal strength was obtained in the woods such as Oriental beech, Alnus glutinosa, Castanea sativa, Oriental spruce and Scotch pine (Akyıldız and Malkoçoğlu, 2001). For the solid-sided and coated particle board which are widely used in the production of furniture, the screw withdrawal capability of three different screws on the surface was analyzed and the highest screw withdrawal strength was obtained in solid particle board.

In the screwed-corner connections, the effects of the screw type, dimension and number on the moment handling performance were analyzed. The screwed distempered connections gave better results than the screwed connections and the connections made from MDF lam gave better results than the connections made from particle board lam. The increase of the moisture amount reduced the screw withdrawal strength from the side and surface in Scotch pine and plywood; the screw withdrawal strength value from the side was obtained higher than the screw withdrawal strength from the surface. The screw withdrawal strength value was obtained higher in plywood than Scotch pine (Wu, 1999). Vassilios and Barboutis (2005) studied the eccentric joints which are commonly used to join particleboard and medium-density fiberboard in cabinet furniture construction. Research reported that face withdrawal

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strengths of the screws differ slightly from manufacturer to manufacturer in particleboard and MDF, whereas withdrawal strengths of screws with plastic sockets differ greatly from one manufacturer to another and the withdrawal capacity of the screws was found to correlate with the density of both particleboard and MDF.

Ithnin and Eckelman (1993) determined the holding strength of large diameter sheet metal screws in the face and edge surfaces of medium density fiberboard and particleboard. Results indicated that the use of pilot holes of the proper diameter significantly increases the holding strength of the screws in the material. In general, pilot holes should be equal to about 80 to 85% of the root diameter of the screw.

For the Oriental beech, Oriental spruce and waferboard the screw withdrawal strengths parallel and perpendicular to the fibers were defined and the highest withdrawal strength was obtained with the screw of 20×35 perpendicular to the fibers in Oriental beech wood (17.670 N mm^{-2}) (Ozçifçi and Doğanay, 1999).

In laminated wood material made of Oriental beech and Scotch pine, the highest screw withdrawal strength was obtained in Oriental beech of 4 mm thickness connected with the screw of 17×17 as 2.32 N mm^{-2}; the lowest screw withdrawal strength was obtained in Scotch pine of 5 mm thickness connected with the screw of 20×45 as 6.74 N mm^{-2} (Ozçifçi, 2001).

Çelebi and Kılıç (2007) searched screw and nail withdrawal strength properties of veneer laminated lumber manufactured from poplar and beech in transverse, radial and tangential directions. Ten and 13 layer laminated samples were produced in different thickness veneers of both species using two types of resins, namely polyvinyl acetate and polyurethane. It was found that layer thickness did not influence the withdrawal strength in transverse direction but strength values increased with increasing specific gravity of the samples in this direction. Overall strength properties in radial direction were found to be higher than that of tangential direction. Based on the statistical analyses resin type did not significantly effect withdrawal strength of both species.

Cai *et al*. (2003) studied the screw withdrawal strength to evaluate the densities of in-sitı wood members. The results show that there is a good correlation relationship between screw withdrawal strength and the density. The result of screw withdrawal test on salvaged joints indicates that there is a good relationship between the static MOE and the dynamic MOE is calculated based on the estimated density.

Atar *et al.* (2007) reported that the impregnation of some softwoods increased the density of wood.

This study was made in order to define the effect of the impregnation process on Scotch pine, Oriental beech and European oak woods with Ba, Bx, Ba+Bx, Imersol-aqua and Timbercare-aqua on the screw withdrawal strength from the cross surface.

MATERIALS AND METHODS

This study was conducted at Gazi University Furniture and Decoration Department Laboratories in 2009.

Wood materials: The woods of Oriental beech (*Fagus orientalis Lipsky*), Scotch pine (*Pinus sylvestris Lipsky*) and European oak (*Quercus petreae Liebl.*) widely used in furniture industry were chosen randomly from timber merchants of İzmir-Kısıkköy in Turkey. Special emphasis is given for the selection of the wood material. Accordingly, non-deficient, proper, knotless, normally grown (without zone line, without reaction wood and without decay and insect mushroom damages) wood materials were selected according to TS 2470 standard (TS 2470, 1976).

Impregnation materials: The wood materials were impregnated with Boric acid (Ba), Borax (Bx), Boric acid+Borax (Ba+Bx), Imersol-aqua (Ia) and Timbercare-aqua (Ta). Boron compounds (boric acid and borax) are obtained from Etibank-Bandırma (Turkey) Boric and Acid Factory. Properties of boric acid (H_3BO_3) is 56.30% ½ B_2O_3, 43.70% H_2O with a molecular weight 61.84, density 1.435 g cm^{-3} and melting point 171°C. Borax ($Na_2B_4O_7.5H_2O$) content is 21.28% Na_2O, 47.80% B_2O_3, 30.92% H_2O with a molecular weight 291.3, density 1.815 g cm^{-3}, melting point 741°C.

Imersol-aqua, used in impregnation process, was supplied from Hemel Hickson Timber Product Ltd., Istanbul, Turkey. Imersol-aqua is submitted to the market in the form of odorless, nonflammable, light straw color, water based solvent having pH of 7 and density of 1.03 g cm^{-3}. It is entirely solved in water and does not create corrosion on the metal surfaces. Imersol-aqua contains 0.5% w/w tebuconazole, 0.5% w/w propiconazole, 0.1% w/w 3-Iodo-2-propynl-butyl carbonate, 0.5% w/w cypermethrin etc. In practice, cutting, drilling, machining etc., processes should be completed in wood materials before preservative treatments. As well as that, humidity of impregnation wood materials should be in equilibrium moisture content involved for the final processing place. Immersion period for softwoods should be at least 6 min. Besides, the quantity of absorbed impregnation material for 1 m^3 wood material should be at least 15 L. After the impregnation process, it can be glued immediately and held 2 days for finishing (Hickson's Timber Impregnations Co., 2000).

Timbercare-aqua is a protective non-harmful to its surrounding and improved for protecting the wood components over the ground level in the constructions and to prevent the destruction by the mushroom and insects in irreversible fixed woods in the replacement operations. It doesn't cause inconvenient and steady smell. The practice is made with brush and 1 L is sufficient for wood surface of 4-5 m^2. As it is uncolored, it doesn't color the surface, but it should be waited for at least 24 h for the surface to fully dry before any process (Keskin and Atar, 2007).

Screws: Screw has a wide range of usage field in furniture and decoration due to its nature to be removed and screwed when necessary and its high capabilities of connection. Generally, they are produced as special-coated with nickel, chrome and cadmium as well as steel, brass and the other metals and alloys. They are categorized according to the material type, the surface process, their shapes and diameters or body dimensions. The screws are connected to the pilot holes drilled in accordance with themselves by turning. The screw shown in Fig. 1 is formed by the helical surfaces cutting each other under a certain angle (TS 61-1, 1994).

In this study, two screws having same length of 50 mm but different diameters as S_1 of 3.5 mm diameter and S_2 of 4 mm diameter were used. The technical specifications of the screws are given in Table 1.

Method

Density of the wood materials: The densities of wood materials, used for the preparation of test specimens were determined according to TS 2472 (TS 2472, 1976). The air-dried of the samples were calculated by the following equation:

$$\delta_{12} = \frac{M_{12}}{V_{12}} \ \text{g cm}^{-3}$$

where, M_{12} is air-dry weight of sample, V_{12} is air-dry volume of sample. The oven-dry density calculated by the following equation:

$$\delta_0 = \frac{M_0}{V_0} \ \text{g cm}^{-3}$$

where, M_0 is oven-dry weight of sample and V_0 is oven-dry volume of sample.

Density designation of the impregnated samples (δo) were calculated by the following equation:

$$\delta_0 = \frac{M_0}{V_0} \ \text{g cm}^{-3}$$

where, M_o is the after-impregnation weight, V_0 is the after-impregnation volume.

Table 1: Technical specifications of S_1 and S_2

Types of screw	S_1	S_2
Screw diameter (mm)	3.50	4.00
Shank diameter (mm)		
D	3.55	4.05
min	3.20	3.70
Root diameter (mm)		
D	2.20	2.55
min	1.60	2.15
Head diameter (mm)		
A	7.50	8.05
min	6.64	7.64
Head load		
H	2.00	2.35
Width of combination drive (mm)		
M	4.00	4.40
Screwdriver		
pH	2.00	2.00
Torque (Nmm)??		
min	20.00	30.00
Driver depth (mm)		
Q	2.16	2.51
min	1.76	2.50
Thread step		
P	1.60	1.80
r	1.80	2.00
a	2.60	2.80
Material	C1018-C1022	
Core hardness (HV)	240–450 HV	
Surface hardness (HV)	min. 450 HV	
Surface hardness depth (mm)	0.05-0.18 mm	0.10-0.23 mm

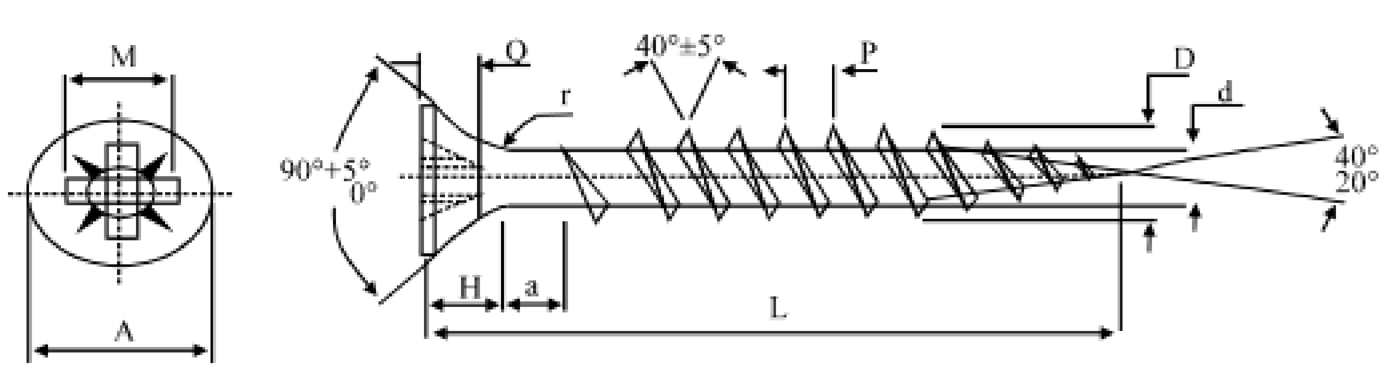

Fig. 1: Screw

Preparation of test specimens: The density and moisture amounts of the tested wood types were determined before the impregnation process. The prepared samples were impregnated in accordance with the conditions mentioned in ASTM D 1413 (ASTM D 1413, 1976) , TS 344 (TS 344, 1981) and TS 345 (TS 345, 1974). In the impregnation with Imersol-aqua, the samples were sunk into the impregnation solution having the packing viscosity as to exceed 1 cm over the top surface for 2 h in medium-term dipping and for 5 days in long-term dipping. In the impregnation with boron compounds, 3 types of solution were prepared as Ba+Bx mixture at the rate of 50% + 50% from Ba of 5%, Bx of 5%, Ba and Bx of 5%. The samples were waited within the solution under the effect of open air pressure for 60 min after vacuum was applied as equivalent to 700 mm Hg^{-1} for 60 min. The weights of the samples were scaled by means of analytical balance having the sensitivity of ±0.01 g before and after the impregnation process and the retention amount (R, kg m^{-3}) of the impregnation material was calculated by the following equation:

$$R = \frac{G.C}{V} \ 10^3$$

Here:

$$G = T_2\text{-}T_1$$

T_2 : After-impregnation sample weight (g)
T_1 : Pre-impregnation sample weight (g)
C : Solution concentration (%)
V : Sample volume (cm³)

The retention amount as % was calculated by the following equation:

$$R(\%) = \frac{T_2 - T_1}{T_1} \times 100$$

The impregnated samples, for the solvent to be vaporized, were waited in an environment having air circulation for 20 days. Afterwards, it was ensured that the moisture of the test samples to be 12% by waiting the 65±3% relative humidity at 20±2°C until it becomes stable weight.

Preparation of samples: In obtaining the test samples, the conditions specified in TS EN 326-1(TS EN 326-1, 1999) and TS EN 13446 (TS EN 13446, 1999) were complied. According to this, pilot holes were drilled as equal to 80% of the thread diameter of the screw to be connected to the cross surfaces of the samples prepared in the dimensions of 50×50×15 mm. After the impregnation process, the samples were waited in the temperature of 20±2°C and in the relative humidity of 65±3% until reaching fixed weight. In connecting the screws, ASTM 1037 and the recommendations of the manufacturers were complied. According to this, the screws were connected to the pilot holes as the screw axis to be perpendicular to the cross surfaces of the samples (ASTM D 1037, 2006). The pilot hole diameters and depths for the screws are given in Table 2.

In the screw withdrawal test, the screws were placed in the entry depth of 8d within a distance of 30 mm at most and they were positioned as shown in Fig. 2.

Test method: The tests were made in the Mechanical Laboratory of the Furniture and Decoration Department of Gazi University, Faculty of Technology with the test mechanism shown in Fig. 3.

The movement speed of the loading head was adjusted as to reach the highest load in a second (15 mm min^{-1}) in the tests. The highest load was recorded by being measured with 1% tolerance. The screw withdrawal strength (N mm^{-2}) was calculated by the following equation:

$$f = \frac{Fmax}{d.\ell p} \left(Nmm^{-2}\right)$$

Here:
f : Screw withdrawal capacity (N mm^{-2})
F_{max} : Highest withdrawal load (N)
l_p : Connector's entry depth (mm)
d : Screw diameter given by the manufacturer (mm)

Table 2: Pilot hole diameters and depths according to screw type

Screw type	Screw diameter (mm)	Pilot hole diameter (mm)	Pilot hole depth (mm)	Screwing depth (mm)
V_1	3.5	2.8	24.5	28
V_2	4.0	3.2	28.0	32

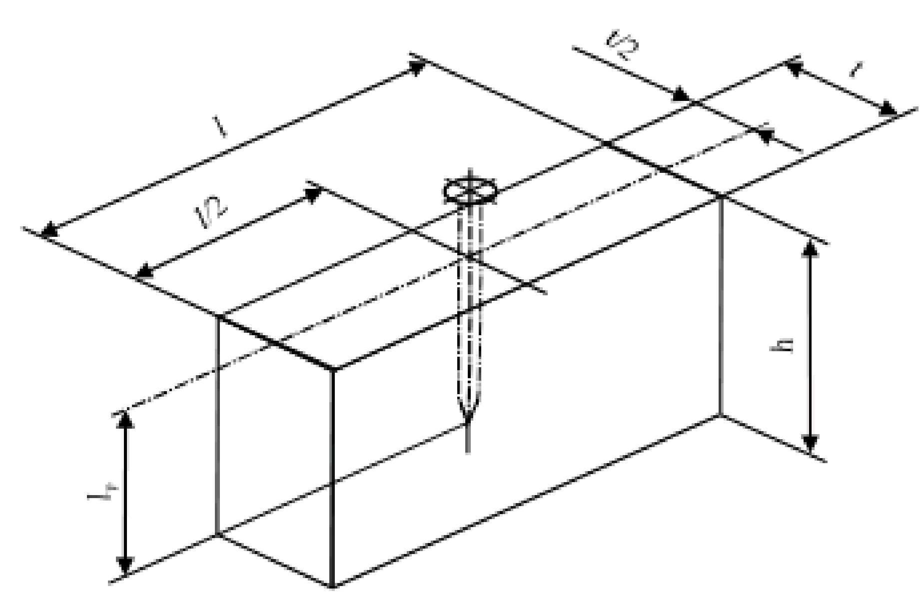

Fig. 2: Screw connection of the samples

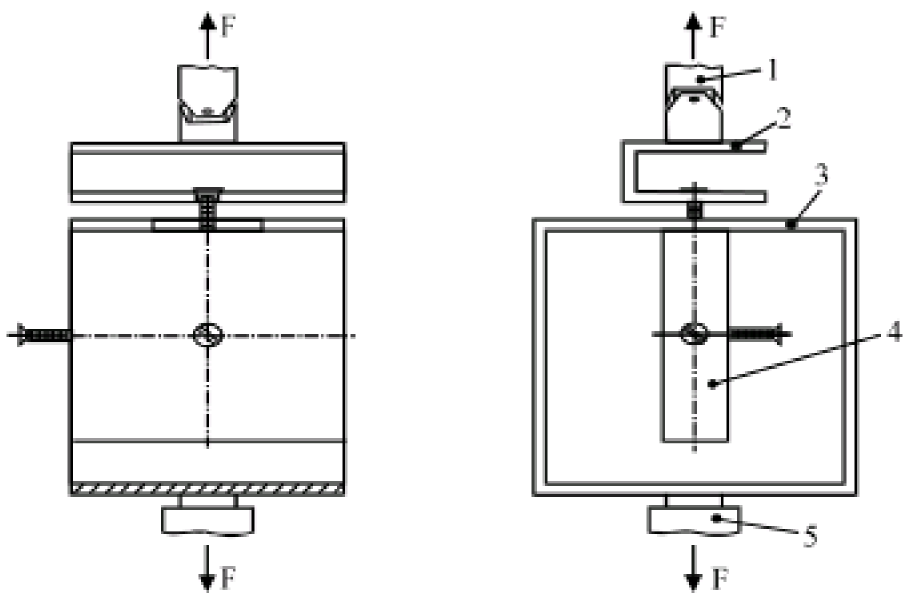

Fig. 3: Test mechanism

Data analysis: By using 3 different types of wood, 6 methods of impregnation having one control, 2 different screw types and 7 for each parameter in total (3×7×2×7) 294 samples were prepared. Multi-variant analysis technique was used in determining the effect of the impregnation process on the screw withdrawal strength in wood material. If the differences between the groups were found significant, Duncan tests were applied to each parameter individually.

RESULTS AND DISCUSSION

There was no significant change occurred in the pH values of the impregnation materials before and after the impregnation process. This may be caused by using fresh solution. The air-dried density (g cm^{-3}) was obtained 0.54 in Scotch pine, 0.62 in Oriental beech and 0.70 in European oak, full-dried density was obtained 0.50 in Scotch pine, 0.57 in Oriental beech and 0.66 in European oak, the air-dried density values after impregnation were obtained 0.56 in Scotch pine, 0.65 in oriental beech and 0.73 in European oak. This results are compatible with the literature. The impregnation process had an increasing effect on the density of the impregnated material as reported by Atar *et al.* (2007). The averages of the retention values of the impregnation materials according to wood type are given in Table 3.

The highest retention amount (kg m^{-3}) was obtained in Oriental beech + I-A_l (487.54), the lowest retention amount was obtained in European oak + Ba (2.94); the highest retention rate (%) was obtained in beech + Ba (114.4), the lowest retention rate was obtained in European oak + Ia (7.41). This result was compatible with the literature. In accordance with this, it can be said that the flow ways in the wood materials were effective as well as the solution concentration of the impregnation material in the retention rates and amounts.

Table 3: Averages of the retention values (kg m^{-3}, %)

Impregnation materials	Oriental beech		European oak		Scotch pine	
	R	R (%)	R	R (%)	R	R (%)
Ba	20.23	114.40	2.94	13.68	3.72	19.87
Bx	19.20	107.47	3.19	15.76	4.22	22.96
Ba+Bx	19.67	109.89	3.24	15.67	4.32	24.87
I-As	170.87	28.52	56.11	7.41	53.30	8.93
I-Al	487.54	82.91	383.66	55.01	326.30	52.44
T-A	160.17	26.54	61.75	8.65	58.19	10.28

Table 4: The average values of the screw withdrawal strength obtained according to wood type, screw type and impregnation material (N mm^{-2})

Types of materials	Statistic	
Wood materials	X	HG*
Oriental beech (I)	3.500	b
European oak (II)	3.675	a
Scotch pine (III)	2.693	c
Screw	X	HG**
Screw (3.5 mm) (S1)	3.222	b
Screw (4 mm) (S2)	3.363	a
Impregnation material	X	HG***
Control (C)	2.940	d
Boric acid (Ba)	3.380	b
Borax (Bx)	3.463	a
Boric acid+Borax (Ba+Bx)	3.204	c
Imersol aqua-short-term (Ias)	3.479	a
Imersol aqua-long-term (Iai)	3.375	b
Timbercare-aqua (Ta)	3.205	c

*Different letter(s) in the columns refer to significant changes among wood materials at 0.05 confidence level (LSD$_{0.5}$ = 0.02667), **Different letter(s) in the columns refer to significant changes among screws at 0.05 confidence level (LSD$_{0.5}$= 0.02178), ***Different letter(s) in the columns refer to significant changes among impregnations materials at 0.05 confidence level (LSD$_{0.5}$= 0.04014), I: Oriental beech, II: European oak, III: Scotch pine, V1: screw (3.5 mm), V2: screw (4 mm), C: Control, Ba: Boric acid, Bx: Borax , Ba+Bx: Boric acid+Borax, I-As: Imersol-aqua (short-term), I-Al: Imersol-aqua (long-term), T-A:Timbercare- Aqua, HG: Degree of homogeny, X: Arithmetical average

The average values of the screw withdrawal strength according to wood type, screw type and impregnation material are given in Table 4. The highest screw withdrawal strength was obtained in European oak (3.675 N mm^{-2}) and the lowest was obtained in Scotch pine (2.693 N mm^{-2}) according to wood material type. The European oak has a higher density than others. The highest screw withdrawal strength was obtained in Bx (3.80 N mm^{-2}) and I-As (3.479 N mm^{-2}) and the lowest in control (2.940 N mm^{-2}) according to the effect of the impregnation material. The highest screw withdrawal strength was obtained in V_2 (3.363 N mm^{-2}) according to screw diameter. This is expected result.

The average values of the screw withdrawal strength obtained according to the dual interactions of wood type, screw type and impregnation material is given in Table 5. The highest screw withdrawal strength was obtained in II+V_1 and the lowest in III + V_2 for the interaction of wood type + screw type. The highest screw withdrawal strength was obtained in Bx + V_1 and the lowest in V_1 + Ta for the interaction of impregnation material+screw type. The

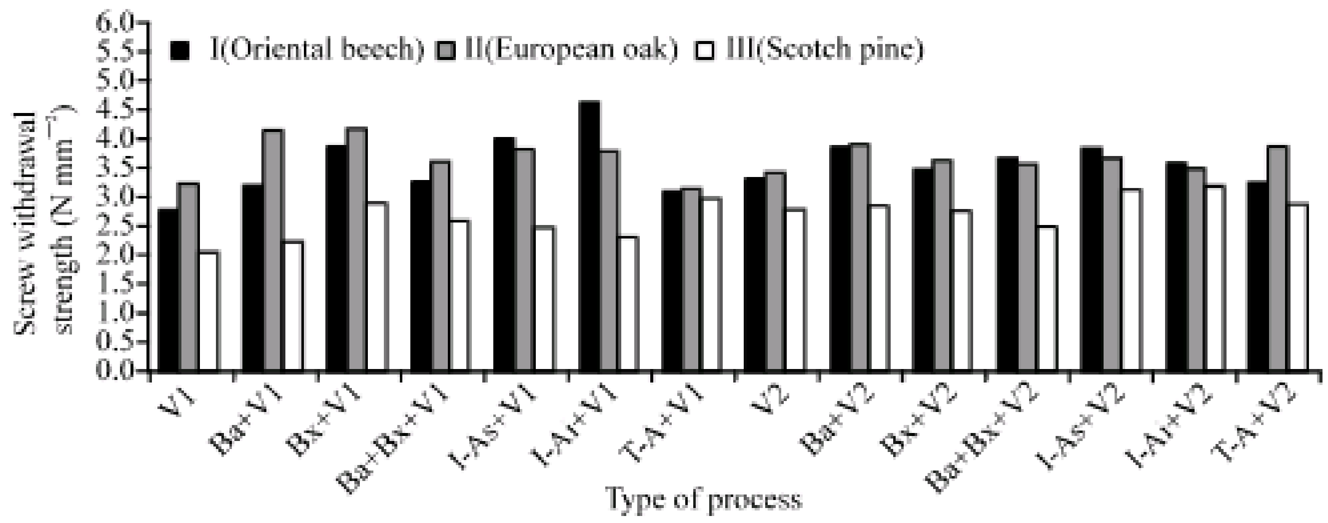

Fig. 4: Screw withdrawal strengths according to wood type, screw type and process type

Table 5: The average values of the screw withdrawal strength obtained according to the dual interactions of wood type, screw type and impregnation material (N mm^{-2})

Types of material	X	HG
*** Wood materials + Screw type**		
I+V1	3.443	d
I+V2	3.571	c
II+ V1	3.704	a
II+ V2	3.648	b
III+ V1	2.519	f
III+ V2	2.868	e
**** Impregnation materials + Screw type**		
V1	2.698	h
Ba+ V1	3.216	f
Bx+ V1	3.646	a
Ba+ Bx + V1	3.175	f
V1+ I-As	3.442	c
V1+ I-Ai	3.300	d
V1+ TA	3.077	g
V2	3.181	f
Ba+ V2	3.543	b
Bx+ V2	3.280	de
Ba+ Bx + V2	3.232	ef
I-As+ V2	3.516	b
I-Ai+ V2	3.450	c
T-A+ V2	3.334	d
*****Wood materials + Impregnation materials**		
I	3.046	j
I+ Ba	3.551	f
I+ Bx	3.671	cd
I+ Ba+ Bx	3.476	g
I+ I-As	3.919	b
I+ I-Ai	3.712	c
I+ TA	3.176	i
II	3.351	h
II+ Ba	4.038	a
II+ Bx	3.894	b
II+ Ba+ Bx	3.573	ef
II+ I-As	3.726	c
II+ I-Ai	3.635	de
II+ T-A	3.516	fg
III	2.421	n
III+ Ba	2.551	m
III+ Bx	2.825	l
III+ Ba+ Bx	2.562	m
III+ I-As	2.793	l
III+ I-Ai	2.778	l
III+ T-A	2.924	k

*Different letter(s) in the columns refer to significant changes among wood materials and screw types at 0.05 confidence level ($LSD_{0.5}$= 0.03772), **Different letter(s) in the columns refer to significant changes among impregnation materials and screw types at 0.05 confidence level ($LSD_{0.5}$= 0.05762), ***Different letter(s) in the columns refer to significant changes among combustion and varnish types at 0.05 confidence level ($LSD_{0.5}$= 0.07057)

Table 6: Multi-variant analysis concerning the effects of the wood type, impregnation material and screw type on the screw withdrawal strength

Source	Degrees of freedom	Sum of squares	Mean square	F-value	Prob
Factor A[a]	2	54.114	27.057	3131.1210	0
Factor B[b]	1	1.450	1.450	167.8454	0
AB	2	2.026	1.013	117.2391	0
Factor C[c]	6	9.180	1.530	177.0515	0
AC	12	6.041	0.503	58.2522	0
BC	6	4.555	0.759	87.8610	0
ABC	12	6.762	0.564	65.2139	0
Error	252	2.178	0.009		
Total	293	86.307			

a: Factor A: wood materials (I: Oriental beech, II: European oak, III: Scotch pine), b: F actor B: screw types V1: screw (3.5 mm), V2: screw (4 mm), c: Factor C: Impregnation materials and control (C= Control, Ba: Boric acid, Bx: Borax, Ba+Bx: Boric acid+Borax, I-As: Imersol-aqua (short-term), I-Al: Imersol-aqua (long-term), T-A: Timbercare-Aqua

highest screw withdrawal strength was obtained in II + Ba and the lowest in III+ Ba for the interaction of wood type+impregnation material. According to the control samples, it can be said that the impregnation materials had an increasing effect on the screw withdrawal strength. This effect was obtained in the samples that were impregnated with boric acid at most. This is a result parallel with the literature.

The results of the multi-variant analysis concerning the effects of wood type, screw type and impregnation material on the screw withdrawal strength are given in Table 6.

The effects of the wood type, impregnated material and screw type on the screw withdrawal strength was significant statistically (α = 0.05). The results of the Duncan test defining that between which groups the difference is significant are given in Table 7.

Before the impregnation process, the highest screw withdrawal strength was obtained in II+V_2 (3.444 N mm^{-2}) and the lowest in III + V_1 (2.053 N mm^{-2}) in the non-impregnated samples; In the impregnated samples the highest screw withdrawal strength was obtained in II+Bx+V_1 (4.193 N mm^{-2}) and II + Ba + V_1 (4.166 N mm^{-2}), but the lowest in III + Ba + V_1 (2.251 N mm^{-2}) as shown in Fig. 4. This result was also expected as compared with the earlier studies.

Table 7: Duncan test results

Process type	X	HG[a]	Process Type	X	HG[a]	Process Type	X	HG[a]
II+ Bx+V1	4.193	a	II+ Bx+V2	3.596	efg	III+ I-As+V2	3.097	k
II+ Ba+V1	4.166	a	I+ I-Ai+V2	3.579	efg	III+ T-A+V1	2.974	l
I+ I-As+V1	4.01	b	II+ I-Ai+ V2	3.551	efgh	III+ Bx+ V1	2.906	lm
II+ Ba+ V2	3.91	c	II+ Ba+Bx+V2	3.533	fgh	III+ T-A+V2	2.874	lmn
II+ T-A+V2	3.879	c	I+ Bx+V2	3.501	gh	III+ Ba+ V2	2.85	mno
I+ Ba+V2	3.87	c	II+ V2	3.444	h	III+ V2	2.79	no
I+ I-Ai+V1	3.846	c	I+V2	3.31	i	I+V1	2.781	no
I+ Bx+V1	3.84	c	I+ Ba+Bx+V1	3.29	i	III+ Bx+V2	2.744	o
II+ I-As+V1	3.829	c	II+V1	3.259	ij	III+ Ba+Bx+V1	2.621	p
I+ I-As+V2	3.827	c	I+ T-A+V2	3.249	ij	III+ Ba+Bx+ V2	2.503	q
II+ I-Ai+V1	3.719	d	I+ Ba+V1	3.231	ij	III+ I-As+V1	2.489	q
I+ Ba+Bx+V2	3.661	de	III+ I-Ai+V2	3.22	ij	III+ I-Ai+V1	2.336	r
II+ I-As+V2	3.624	def	II+ T-A+V1	3.154	jk	III+ Ba+V1	2.251	r
II+ Ba+Bx+V1	3.613	defg	I+ T-A+V1	3.103	k	III+V1	2.053	s

[a]:Different letters in a column refers to significant differences among the different interactions of wood materials, screws and impregnation materials at 0.05 confidence level ($LSD_{0.5}$: *LSD: 0.07057), I: Oriental beech, II: European oak, III: Scotch pine, S1: Screw (3.5 mm), S2: Screw (4 mm), C: Control, Ba: Boric acid, Bx: Borax, Ba+Bx: Boric acid+Borax, I-As: Imersol-aqua (short-term), I-AI: Imersol-aqua (long-term), T-A: Timbercare-Aqua

CONCLUSIONS

According to wood type, the highest screw withdrawal strength was obtained in European oak (3.675 N mm^{-2}) and the lowest was obtained in Scotch pine (2.693 N mm^{-2}). The screw withdrawal strength was obtained 23% higher in European oak than Scotch pine and 5% higher in Oriental beech. This may be caused by the density difference of the woods. This result is parallel with the earlier studies. The highest screw withdrawal strength was obtained in I-As (3.479 mm^{-2}) and the lowest was obtained in Ba + Bx (3.204 N mm^{-2}) for the effect of the impregnation material type. The screw withdrawal strengths were obtained 13% higher in Ba, 15% higher in Bx, 8% higher in Ba + Bx, 16% higher in I-As, 13% higher in I-A_1 and 8% higher in T-A according to the control sample. The impregnation materials had an increasing impact on the screw withdrawal strength. This may be caused by the increased density of wood material by the impregnation materials. The highest screw withdrawal strength was obtained in V_2 (3.363 N mm^{-2}) and the lowest was obtained in V_1 (3.222 N mm^{-2}) according to screw diameter. The screw withdrawal strength was obtained 11% higher in V_2 than V_1. The highest screw withdrawal strength was obtained in European oak + S_1 (3.704 N mm^{-2}) and the lowest was obtained in Scotch pine + S_2 (2.519 N mm^{-2}) according to wood type and screw diameter combination. The screw withdrawal strength was obtained higher in the impregnated woods than non-impregnated woods according to wood type+impregnation material and impregnation material+screw diameter combinations. The highest screw withdrawal strength was obtained in II + Bx + V_1 (4.193 N mm^{-2}) and the lowest was obtained in III + Ba + V_1 (2.251 N mm^{-2}) according to the interaction of wood type, impregnation material and screw diameter. According to those results, it can be said that screw withdrawal strength is higher in the hardwoods due to the difference in densities of the woods. Thus, the screw withdrawal strength was obtained higher in European oak wood having high density than the others. The impregnation process increased the screw withdrawal strength. This may be due to entering of impregnation material into the cell wall gap within the wood. According to these, impregnation of wood with Bx and screwing with V_1 on the cross surface may provide an advantage.

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