

## The Possibilities of Using Boron Compounds in Environmentally Friendly Furniture Industry

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### ABSTRACT

This study was performed to determine the effects of impregnation with boron compounds and water repellents on the dimensional stability of wood. For this purpose, the test specimens prepared from scotch pine (*Pinus sylvestris* L.) wood which met the requirements of TS 345 and TS 1476 standards procedures were single, double or multi treated according to ASTM D 1413-76 standard procedure with some boron compounds such as boric acid (Ba) and borax (Bx), some water repellent materials (WRM) such as styrene, methyl methacrylate, izocyanate, polyethyleneglychol-400 (PEG-400), and some commercial impregnation materials such as Tanalith-CBC (T-CBC), ammonium sulfate (AS), diamonium phosphate (DAP), and vacsol. As a result, secondary treatment with WRM decreases amount of leached material. Water absorption ratio of wood was lowest in the treatment only with WRM, boron compounds and in secondary treatment of PEG-400 with WRM. Order of convenience for dimensional stability was like WRM>(Ba+Bx)+WRM>PEG-400+WRM>commercial impregnation materials. Order of convenience for volumetric shrinkage efficiency was like (Ba+Bx)+WRM>PEG-400+WRM>AS, DAP, T-CBC. WRM was found more successful in leaching prevention when used as a secondary treatment after PEG-400. So, the wood which will be used in open air and high relative humidity conditions, secondary impregnation with WRM is recommended.

**Keywords:** Boron compounds, dimensional stability, impregnation, leaching, scotch pine

### Çevre Dostu Borlu Bileşiklerin Mobilya Endüstrisinde Kullanım Olanakları

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### ÖZET

Bu çalışmada, odun koruma ve çalışmayı azaltma amacıyla kullanılan bazı kimyasal maddelerin empenye maddesi yıkanması ve hacimsel stabiliteye etkileri araştırılmıştır. Bu maksatla, sarıçam (*Pinus sylvestris* L.) odunundan TS 345 ve TS 1476'ya göre hazırlanan örnekler, ASTM D 1413-76 esaslarına göre; Borik asit (Ba), Boraks (Bx), Polietilenglikol 400 (PEG-400) ve bazı borlu bileşiklerden; Ba+Bx, Ba+Bx+St, Ba+Bx+MMA, Ba+Bx+St+MMA, su itici maddelerden (SİM); Stiren (St), Metilmetakrilat (MMA), İzosiyanat (ISO), ticari empenye maddelerinden; Tanalith-CBC (T-CBC), Amonyum sülfat (AS), Diamonyum fosfat (DAP) ve Vacsol (V) ile tekli, ikili veya çoklu işlemler halinde empenye edildikten sonra AWPA N-10 ve ASTM D 1413-76 esaslarına uyularak 6, 24, 48 ve 72 saat süreyle yıkanma etkisinde bırakılmıştır. Yıkanma etkisi sonucu boyutsal çalışma ve empenye maddesi yıkanma miktarlarına göre; yıkanma süresi arttıkça yıkanan madde miktarı azalmıştır. Borlu bileşikler ve bunların ikincil SİM işlemleri uygulamaları yıkanan madde miktarını azaltmıştır. Su alma oranları zamana bağlı olarak artmakta, en az su alma oranı SİM'lerin tek başına kullanımında ve Borlu bileşikler ile PEG-400'ün SİM'ler ile ikincil işlemler empenyesinde elde edilmiştir. Odunda stabilite sağlamada uygunluk sırası; SİM>Ba+Bx+SİM>PEG-400+SİM>Ticari empenye maddeleri şeklinde olmuştur. Hacimsel daralmayı azaltıcı etkenlik bakımından uygunluk sırası; (Ba+Bx)+SİM>PEG-400+SİM>AS, DAP, T-CBC şeklindedir. Su itici

etkenlik değeri bakımından, PEG-400'ün SİM'li uygulamaları başarılı bulunmuştur. SİM'lerin yıkanmayı engelleme etkenliğinin PEG-400'lü gruplarla emprenyede daha başarılı olduğu söylenebilir. Buna göre; açık hava yada yüksek nem şartlarında kullanılacak ve su etkisi ile odundan yıkanarak uzaklaşabilecek suda çözünen borlu bileşikler ile emprenye edilmiş sarıçam odununda emprenye maddesi yıkanmasını engellemek, su alma oranını azaltmak, su itici etkenliği arttırmak ve boyutsal stabiliteyi düzenlemek amacıyla SİM'lerle ikincil emprenye uygulamaları önerilebilir.

**Anahtar kelimeler:** Borlu bileşikler, emprenye, mobilya endüstrisi, stabilite, su iticiler, yıkanma

## INTRODUCTION

Impregnation of wood with chemical materials is absolutely necessary to protect from insects, fungus etc. in many applications (Williams 1990). Boron compounds are the impregnation materials preserving wood from biotic damages but leaching from wood restricts the usage of it (Murphy et al. 1990). It is known that, in the leaching of impregnation material from wood, concentration of impregnation material, duration of impregnation, properties of wood, ratio of extractive material, acidity of water etc. are important factors (Richardson 1987). The shrinkage of wood decreases by % 70 when impregnated with high concentration of salt and natural sugar solutions (Stamm and Honsen 1935; Stamm 1969). Water absorption ratio of Scotch pine was found %40 when impregnated with % 0,5 paraffin, %10 hydrogenised resin ester and % 9,5 white sprit (Voulgaridis 1986). It has been reported that bulking materials (PEG-400, PEG-1000 etc.) widening cell walls and additionally forming chelate by using together with boron compounds or in secondary impregnation process play an important role in the development of dimensional stability (Hofors 1990). It has been reported also that impregnation with boron compounds develops some of the technological properties and additional treatment with WRM avoids leaching (Yıldız 1992).

In this study, the effects of secondary impregnation of wood with WRM to avoid the leaching of boron and to develop the

dimensional stability by decreasing shrinkage or swelling have been determined.

## MATERIALS and METHODS

Test specimens were prepared from Scotch pine wood obtained from Trabzon-Çaykara Forest Administration. The logs were cut according to TS 4176 (1984) standard procedures. Anti blue was applied on surfaces of logs to prevent coloring after they were brought to the laboratory. Boron compounds obtained from ETIBANK-Bandırma Borax and Acid Factories, vinyl monomers from PETKIM-Izmit Refinery Co., and POLISAN Chemical Industry Co., PEG-400 from SHELL Petroleum Co. and other materials from market.

### Preparation of test specimens

TS 345 (1974) standard procedures were applied in the preparation of test specimens. The logs are cut from a section 2 m height from the bottom and under the top of main stem. Prism cut in radial direction from the sapwood, were kept in  $20\pm 2$  °C temperature and  $65\pm 3\%$  relative humidity conditions up to reaching 12% humidity. The air-dry, prismatic specimens with a dimension of 2cmx2cmx50cm were impregnated. The part of 2.5cm length was cut from the top of impregnated specimens. From the remaining part, leaching test specimens were cut into the dimensions of 2cmx2cmx2cm.

### Impregnation solutions

I.Commercial impregnation materials: T-CBC, AS, DAP, V

II. a) Water solutions of boron compounds (for single treatment): Ba+Bx (7:3 weight/weight) b) Water solutions of boron compounds+WRM (for double treatment): (Ba+Bx)+St, (Ba+Bx)+MMA, (Ba+Bx)+(St+MMA)

III. Materials containing PEG (bulking)+WRM: PEG-400, PEG-400+St, PEG-400+MMA, PEG-400+(St+MMA), PEG-400+ISO

IV. Water repellent materials (WRM): St, MMA, (St+MMA), ISO

### Method of impregnation

In the process of impregnation, ASTM D 1413-76 (1976) standard procedures was applied. The specimens were processed with pre-vacuum of 760-mm Hg<sup>-1</sup> for 60 minutes and then put into the impregnation solution in perpendicular position under the atmospheric pressure for 60 minutes. Impregnated specimens were kept under air circulation for 20 days for vaporization of solvent and then put into the drying oven at the temperature of 103±2 °C for full-dry. The full-dry, impregnated specimens were cooled in desiccators containing CaCl<sub>2</sub>, for 12 hours and weighed at the analytic balance of 0,01g sensitivity. Moreover, the specimens impregnated with PEG, were kept at 60-70 °C temperature for 5-7 days to avoid impregnation chemicals leaking out of the wood. The retention amount R, (kg/m<sup>3</sup>) and retention ratio R (%) was calculated by the formula (Yalınkılıç et al., 1997):

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

$$R(\%) = \frac{Moes - Moe\check{s}}{Moe\check{s}} \cdot 100$$

$$G = T_2 - T_1$$

T<sub>1</sub>: Weight of specimen before impregnation

T<sub>2</sub>: Weight of specimen after impregnation

V: Volume of specimen

C: Concentration of solution (%)

M<sub>ocs</sub>: Oven dry weight of specimen after impregnation

M<sub>ocö</sub>: Oven dry weight of specimen before impregnation

Test plan and qualification of impregnation solutions are given in Table 1.

### Leaching test

Leaching test was done according to ASTM D 1413-76 standard procedures. After each leaching process (6, 24, 48, 72 hours), the specimens were taken from distilled water and oven dried in a drying oven at the temperature of 103±2 °C. The full-dry specimens are weighed and measured in dimension. The amount of leached materials (ALM %), ratio of water absorption (RWA %), the effectiveness of water repellents (EWR %), volumetric change in wet condition (VCWC %), volumetric change after leaching as compared with oven-dry dimensions (VCDC), efficiency of decreasing the shrinkage (EDS %) and expansion (EDE %) values are calculated by the formulas:

$$ALM(\%) = \frac{Moi - Mos}{Moi} \cdot 100$$

$$RWA(\%) = \frac{Mrs - Moi}{Moi} \cdot 100$$

$$EWR(\%) = \frac{(SAOK - SAOT)}{SAOK} \cdot 100$$

$$VCWC(\%) = \frac{Vysh - Vyöh}{Vyöh} \cdot 100$$

$$VCDC(\%) = \frac{Voi - Vos}{Voi} \cdot 100$$

$$EDE(\%) = \frac{Gk - Gt}{Gk} \cdot 100$$

$$EDS(\%) = \frac{Dk - Dt}{Dk} \cdot 100$$

M<sub>oi</sub>: Oven dry weight after impregnation

M<sub>os</sub>: Oven dry weight after leaching process

M<sub>rs</sub>: Wet weight after leaching process

Saok: Ratio of water absorption by control specimen (%)

Saot: Ratio of water absorption by test specimen (%)

$V_{ysh}$ : Wet volume after leaching process

$V_{yöh}$ : Humid volume before leaching process

$V_{oi}$ : Oven dry volume before leaching process

$V_{os}$ : Oven dry volume after leaching process

Dk: Volumetric shrinkage of control specimen after leaching period (%)

Dt: Volumetric shrinkage of test specimen after leaching period (%)

Gk: Volumetric expansion of control specimen after leaching period (%)

### Data analysis

The statistical results were given by computer software, SPSS 12.0 for Windows. Multiple Variance Analysis (MANOVA) Method is used to determine the impact of impregnation material on R, ALM, RWA, EWR, VCWC, VCDC, EDS and EDS and Duncan's Test Method to determine differences between the groups.

**Table 1** Impregnation test plan and solution qualifications

Mat. Group	Representing Material	Imp. Exp. No	Imp. Proc. No	Order of Process		Const of solt. (%)		Solvent Mat. 1. Imp.	pH		Density (g/ml)		Bae (%)		°C
				1.Process	2.Process	1.Impreg	2.Impreg		Bi	Ai	Bi	Ai	Bi	Ai	
<b>I.Comp. Group</b>	Bor. Comp.	1	1	T-CBC		13		Ds	2.48	2.79	1.08	1.08	48.2	48.2	25
	Amon. Comp.	2	1	AS		13		Ds	4.55	4.06	1.07	1.07			25
	Phos. Comp.	3	1	DAP		13		Ds	6.64	6.70	1.07	1.07			25
	Org. solution	4	1	V		100		Ds	5.91	6.00	0.81	0.81			25
<b>II.Boron Comp.</b>	Fire preventives, insecticides, Funguses wood protectors	5	1	Ba+Bx 7/3 w/w		13	-	Ds	7.86	7.91	1.11	1.11	62.3	62.3	25
		6	2	Ba+Bx 7/3 w/w	St	13	100	Ds	7.86	7.91	1.11	1.11	62.3	66.8	25
		7	2	Ba+Bx 7/3 w/w	MMA	13	100	Ds	4.14	4.10	0.91	0.91	62.3	66.8	25
		8	2	Ba+Bx 7/3 w/w	St+MMA	13	70:30	Ds	7.86	7.91	1.11	1.11	62.3	66.8	25
<b>III. PEG</b>	PEG-400	9	1	PEG-400		100			5.67	5.60	1.12	1.12			25
		10	2	PEG-400	St	100	100		5.67	5.60	1.12	1.12			25
		11	2	PEG-400	MMA	100	100		4.14	4.10	0.91	0.91			25
		12	2	PEG-400	St+MMA	100	70:30		5.67	5.60	1.12	1.12			25
		13	2	PEG-400	ISO	100	100		7.41	7.85	1.22	1.22			25
<b>IV.WRM</b>	Water Repellent Materials	14	1	St		100			5.70	5.65	1.12	1.12			25
		15	1	MMA		100			4.14	4.10	0.91	0.91			25
		16	1	St+MMA		70:30			7.41	7.85	1.22	1.22			25
		17	1	ISO		100			5.70	5.65	1.12	1.12			25
								4.60	4.60	1.21	1.21			25	

w/w: weight/weight, DS: Distilled water, Bae: Boric acid equivalence, Bi: Before impregnation, Ai: After impregnation, T-CBC: Tanalith-CBC, AS: Ammonium sulfate, DAP: Diamonium phosphate, V: Vacsol, Ba: Boric acid, Bx: Borax, PEG-400: Poliethyleneglychol-400, MMA: Methyl metacrylat, St: Styrene, ISO: Isocyanides, Note: In each test, two groups were used, each having 12 specimens

**RESULTS AND DISCUSSIONS**

**Retention**

Retention values of impregnation material are given in Table 2. Retention is found the highest in WRM group and it was the lowest in commercial impregnation materials. Order of retention amount is as WRM>PEG-

400>boron compounds>Commercial impregnation materials.

**The Leached Amount of Impregnation Material**

The leached amount of impregnation material and retention amount in oven-dried specimens are given Table 3.

**Table 2** Retention amount of impregnation material

Grp. No	Imp. No	Chemical Materials	Retention (kg/m <sup>3</sup> )			Retention Ratio %						Total Retention	
			x	Ss	HG	1 <sup>st</sup> impregnation			2 <sup>nd</sup> impregnation			x	Ss
						x	Ss	HG	x	Ss	HG		
I.	1	T- CBC	19.38	2,27	N	10.9	1.3	G				10.9	1.3
	2	AS	58.32	18.28	J	14.1	1.9	E				14.1	1.9
	3	DAP	30.84	11.56	L	11.2	0.7	G				11.2	0.7
	4	V	113.88	7.65	I	28.6	19.1	C				28.6	19.1
II.	5	Ba+Bx	41.64	7.77	K	16.4	12.2	E				16.4	12.2
	6	(Ba+Bx)+St	26.77	113.81	M	19.4	10.7	E	31.1	15.3	B	50.5	16.5
	7	(Ba+Bx)+MMA	113.77	82.98	I	4.8	13.9	I	13.3	9.5	D	18.1	10.6
	8	Ba+Bx)+St+MMA	213.49	78.56	E	10.0	11.1	G	13.6	9.5	D	23.6	5.9
III.	9	PEG-400	113.88	7.65	I	13.1	1.5	F				13.1	3.5
	10	PEG-400+St	208.97	12.73	F	13.1	0.4	F	5.3	3.2	G	18.4	2.3
	11	PEG-400+MMA	195.87	60.75	G	11.8	1.7	G	6.1	6.6	F	17.9	8.3
	12	PEG-400+S+MMA	232.80	10.23	C	11.9	0.5	G	11.3	0.6	E	13.2	4.1
	13	PEG-400+YSO	233.98	37.67	C	12.6	0.8	F	14.3	1.3	C	27.7	0.7
IV.	14	St	374.50	75.53	A	56.3	15.5	A				56.3	15.5
	15	MMA	186.09	67.34	H	24.1	14.2	D				24.1	14.2
	16	St + MMA	225.00	105.00	D	35.7	19.6	B				35.7	19.6
	17	ISO	276.25	62.09	B	22.3	10.8	D				22.3	10.8

x : Average, Ss : Standard deviations, HG: Homogeneous groups

**Table 3** The leached amount of impregnation material (ALM %)

No	Impregnation Materials and Process	I (6 hours)			II (24 hours)			III (48 hours)			IV (72 hours)			Total ALM (%)
		x	HG	Ss	x	HG	Ss	x	HG	Ss	x	HG	Ss	
1	Control	0.20	J	0.20	0.12	L	0.12	0.10	I	0.10	0.35	G	0.11	0.45
2	T- CBC	0.19	J	0.19	0.80	H	0.04	2.10	C	0.13	0.15	H	0.11	3.20
3	AS	1.48	B	0.18	4.02	C	1.05	4.56	B	1.83	4.61	B	0.26	14.65
4	DAP	1.46	B	0.95	0.37	J	0.03	1.27	D	0.50	0.37	G	0.14	3.47
5	V	0.45	G	0.25	0.84	H	0.46	0.55	F	0.17	1.12	E	0.45	2.96
6	(Ba+Bx)	1.44	B	1.21	4.01	C	1.63	1.30	D	1.02	2.19	D	0.12	8.94
7	(Ba+Bx) + St	0.10	K	0.10	0.73	I	0.17	0.68	E	0.26	0.74	F	0.52	2.25
8	(Ba+Bx) + MMA	0.41	H	0.06	1.36	F	0.18	0.52	F	0.35	1.45	E	0.09	3.74
9	(Ba+Bx)+S +MMA	0.31	I	0.09	2.80	E	0.65	0.63	E	0.18	0.85	G	0.39	4.59
10	PEG-400	3.50	A	0.08	12.10	A	0.10	8.53	A	0.74	8.66	A	0.93	32.79
11	PEG-400 + St	0.50	F	0.00	0.74	I	0.04	1.16	D	0.11	0.33	G	0.01	2.73
12	PEG-400 + MMA	0.87	D	0.15	2.83	E	0.08	1.35	D	3.65	2.47	D	0.05	7.52
13	PEG-400+St+MMA	1.58	B	0.18	4.41	B	0.77	2.37	C	0.12	3.00	C	0.78	11.36
14	PEG-400 + ISO	1.08	C	2.63	3.69	D	0.77	2.05	C	3.65	1.50	E	0.48	8.32
15	St	0.64	E	0.38	0.13	K	0.13	0.32	G	0.06	0.57	F	0.43	1.66
16	MMA	0.28	I	0.28	0.74	I	0.02	0.70	E	0.28	0.45	G	0.15	2.18
17	St+MMA	0.37	H	0.42	0.34	J	1.12	0.21	H	0.10	0.56	F	0.45	1.48
18	ISO	0.39	H	0.03	0.93	G	0.20	0.57	F	0.34	0.12	H	0.88	2.21

In each of two test groups, 12 specimens were used (Total : 17 x 2 = 34 group x 12 specimens / group = 408specimens, p ≤0,05)

According to the duration of leaching process, the amount of leached material was found highest in PEG-400 and lowest in (Ba + Bx) + St at 1<sup>st</sup> period, highest in PEG-400 and lowest in St at 2<sup>nd</sup> period, highest in PEG-400 and lowest in St + MMA at 3<sup>rd</sup> period, highest in PEG-400 and the lowest in T-CBC and ISO at 4<sup>th</sup> period. According to these results, the amount of leached material decreased as the duration of leaching process gets longer and this decrease happened especially in the first two periods (6-24 hours). In boron compounds and secondary treatment with WRM, the amount of leached

material was decreased as compared with single treatment with PEG-400 and secondary treatment with WRM. The lowest amount of leached material was observed in single treatment of WRM and highest in single treatment of PEG-400. The order of convenience for total amount of leached material is like WRM>boron compounds + WRM>commercial impregnated materials>PEG-400 + WRM.

**Ratio of Water Absorption**

Cumulative ratio of water absorption for leaching periods is given Table 4.

**Table 4** RWA (%) for leaching periods

No	Impregnation Materials and Process	I (6 hours)			II (24 hours)			III (48 hours)			IV (72 hours)		
		x	HG	Ss	x	HG	Ss	x	HG	Ss	x	HG	Ss
1	Control	80.5	A	13.75	95.3	A	3.85	100.5	A	2.42	110.6	A	0.40
2	T-CBC	46.2	E	3.20	61.2	D	1.82	79.4	B	0.55	74.9	E	1.55
3	AS	47.6	E	1.65	61.0	D	2.60	68.3	D	0.50	71.9	E	1.10
4	DAP	76.3	B	19.10	86.0	B	4.60	70.7	C	1.20	81.4	D	6.85
5	V	28.6	H	0.60	46.4	F	1.25	61.3	E	1.50	51.6	H	8.60
6	Ba+Bx	63.3	C	5.05	71.0	C	1.05	81.8	B	0.40	103.0	B	2.00
7	(Ba+Bx) +St	25.7	I	3.00	43.7	G	6.80	34.6	H	3.05	55.8	G	2.70
8	(Ba+Bx) + MMA	29.6	G	10.00	30.8	I	9.20	54.5	F	5.30	42.2	I	33.3
9	(Ba+Bx) + St +MMA	30.8	G	1.30	57.3	E	6.51	76.7	C	0.75	74.2	E	2.15
10	PEG-400	54.3	D	0.50	67.5	D	4.40	81.7	B	11.40	93.3	C	6.70
11	PEG-400 + St	17.9	J	0.60	42.2	G	7.20	32.2	H	3.00	48.7	H	7.01
12	PEG-400 + MMA	45.3	E	10.40	37.7	H	3.40	45.4	G	12.30	36.8	J	3.20
13	PEG-400 +St + MMA	42.8	F	3.65	50.0	E	8.30	53.5	F	5.00	59.3	F	13.00
14	(PEG-400 + ISO	24.5	I	2.70	37.3	H	1.05	57.7	E	7.90	50.4	H	8.02
15	St	25.2	I	12.00	26.0	J	6.15	27.7	I	21.00	50.0	H	21.50
16	MMA	30.0	G	14.70	49.2	E	6.10	69.0	D	11.00	58.7	F	2.90
17	St + MMA	25.0	I	9.50	46.9	F	0.65	48.3	G	10.30	55.6	G	6.40
18	ISO	29.2	G	1.55	73.1	C	0.12	67.2	D	0.75	60.5	F	5.11

In each of two test groups, 12 specimens were used ( Total : 17 x 2 = 34 group x 12 specimens / group = 408specimens, p ≤ 0,6)

specimens by leaching VCDC (%) is given in Table 5.

**Volumetric Change:** Volumetric change in wet test specimens (VCWC %) and oven-dry

**Table 5** Volumetric change in wet test specimens (VCWC %) and oven-dry specimens by leaching (VCVC %)

Test No	VCDC	I (6 hours)			II (24 hours)			III (48 hours)			IV (72 hours)		
		x	HG	Ss	x	HG	Ss	x	HG	Ss	x	HG	Ss
1	Control	+2,8	J	0.00	-6.40	A	0.40	+0.97	E	0.60	-0.49	DH	0.37
2	T-CBC	-1.45	DE	1.82	-0.12	I	0.10	+2.99	C	1.15	-1.44	FG	0.46
3	AS	+4	B	1.19	+3	D	0.11	+4.89	AB	0.85	+2.38	E	0.16
4	DAP	+0.9	E	0.80	-4.15	C	0.71	-2.32	CD	1.25	-0.48	GH	0.05
5	V	-1.74	D	1.70	-0.39	J	0.16	-4.14	B	0.05	+6.42	B	1.39
6	Ba+Bx	-1.29	DE	0.83	-6.91	A	1.48	-1.74	D	1.51	+3.31	D	2.49
7	(Ba+Bx) + MMA	-0.28	EF	0.28	-0.17	I	0.06	-3.96	BC	0.32	+7.56	A	6.04
8	(Ba+Bx) + St	-1.74	D	0.90	-6.01	B	2.38	-1.72	D	0.79	-4.09	C	5.04
9	(Ba+Bx) + St + MMA	-0.65	E	0.45	-1.56	G	0.44	-5.92	A	2.06	+0.28	H	0.05
10	(PEG-400	-2.67	C	1.51	-2.03	EF	1.12	-2.57	C	2.00	+3.37	D	0.06
11	PEG-400 + St	-1.26	DE	-0.21	-1.15	A	0.12	-0.29	F	0.05	+4.02	C	1.19
12	PEG-400 + MMA	-0.22	EF	0.21	-0.63	H	0.40	-0.78	E	0.30	-0.85	G	0.06
13	PEG-400 + St+ MMA	-1.38	DE	1.21	-2.77	E	0.14	-0.96	E	0.50	-2.52	E	2.50
14	PEG-400 + ISO	-3.73	BC	0.80	-6.35	AB	0.65	-2.66	C	1.05	+5.89	B	1.42
15	St	-2.20	CD	1.76	-3.80	CD	2.39	-1.10	E	0.09	+1.36	FG	1.13
16	MMA	-5.09	A	4.98	-4.60	C	0.08	-0.11	F	0.10	+3.82	CD	2.88
17	St+MMA	-4.03	B	0.13	-3.78	D	0.08	-1.40	DE	0.86	-1.86	EF	1.30
18	ISO	-1.88	DE	0.53	-2.66	E	1.24	-1.85	D	1.17	-1.77	F	1.70
Test No	VCWC	I (6 hours)			II (24 hours)			III (48 hours)			IV (72 hours)		
		x	HG	Ss	x	HG	Ss	x	HG	Ss	x	HG	Ss
1	Control	10.2	C	2.41	10.6	B	0.3	11.3	B	0.55	12.14	B	1.59
2	T- CBC	5.9	E	1.74	8.5	CD	0.7	8.06	CD	1.01	6.90	E	2.80
3	AS	5.7	E	2.11	4.9	E	0.38	6.70	E	2.40	5.40	EF	1.12
4	DAP	2.6	GH	2.36	2.9	G	1.58	3.70	F	1.13	5.90	EF	0.40
5	V	2.8	GH	0.4	4.5	E	1.7	7.80	D	0.55	4.70	G	2.50
6	Ba + Bx	11.9	B	2.3	10.8	B	2.3	9.5	C	1.40	8.9	CD	1.10
7	(Ba + Bx) + St	11.0	B	0.4	9.2	C	2.2	9.4	C	14.0	8.7	CD	8.70
8	(Ba+Bx) + MMA	10.9	C	0.6	8.7	CD	4.2	8.5	CD	2.50	7.2	E	1.12
9	(Ba+Bx) + St + MMA	8.14	D	0.12	9.12	C	0.7	10.2	CB	0.80	10.9	BC	2.00
10	PEG-400	4.11	F	3.1	4.8	E	1.05	5.3	E	0.40	6.2	E	0.60
11	PEG-400 + St	2.3	H	2.4	3.6	F	0.61	3.96	G	1.76	4.20	G	4.10
12	PEG-400 + MMA	3.1	G	0.15	3.16	F	2.05	4.00	F	1.00	3.89	HG	0.10
13	PEG-400 + St +MMA	1.72	I	3.9	2.13	G	0.01	3.50	G	2.10	3.85	HG	0.25
14	PEG-400 + ISO	3.12	G	1.1	2.8	G	2.9	3.12	G	0.10	4.32	G	1.50
15	St	4.9	E	1.8	8.6	CD	4.8	11.3	B	5.10	9.70	C	4.20
16	MMA	12.5	A	2.78	13.72	A	7.1	14.2	A	2.15	15.92	A	6.90
17	St + MMA	9.13	C	2.1	11	AB	6.0	11.6	B	1.82	13.0	B	3.40
18	ISO	4.13	F	6.12	8.5	CD	1.15	11.3	B	3.20	10.8	BC	1.52

(-) means shrinkage where as (+) means expansion in volume.



Impregnation either with PEG-400 or PEG-400+WRM affects dimensional stability positively. Order of dimensional stability is like WRM>(Ba+Bx) + WRM>PEG-400 + WRM> commercial impregnation material.

**Effectiveness in Decreasing Shrinkage Ratio**

The difference between the volumetric shrinkage of control and test specimen after leaching period over the test specimen, called Efficiency in Decreasing Shrinkage Ratio is given Table 6. Efficiency in Decreasing Expansion (EDE) is just opposite of EDS, so is not given in Table 6.

**Table 6** Efficiency in decreasing shrinkage (EDS %) and expansion (EDE%)

No	Impregnation Materials and Process	I (6 hours)		II (24 hours)		III (48 hours)		IV (72 hours)	
		x	H G	x	H G	x	H G	x	H G
1	Control	-		-		-		-	
2	T-CBC	+0.49	H	-7.77	I	+19.76	F	-19.07	BC
3	AS	-27.90	D	-8.35	I	+3.43	I	-15.85	C
4	DAP	-10.32	F	+30.61	C	+7.80	H	+24.92	B
5	V	+76.26	A	+18.75	EF	+33.09	C	-13.57	C D
6	(Ba+Bx)	-32.67	C	+7.89	I	+23.74	E	-13.83	C D
7	(Ba+Bx) + St	+35.35	C	+37.09	BC	+50.08	AB	+5.84	H
8	(Ba+Bx) + MMA	+22.74	DE	+7.77	I	+37.47	C	+13.50	C D
9	(Ba+Bx) +St + MMA	+58.49	B	+40.36	B	+53.46	A	+15.65	C
10	PEG-400	-19.07	E	+16.47	G	+11.90	G	+16.72	C
11	PEG-400 + St	+35.05	C	+25.82	D	+9.24	G H	-11.95	D
12	PEG-400 + MMA	+14.80	F	+7.36	I	+29.44	CD	+3.69	G
13	PEG-400+St + MMA	+17.58	E	-25.64	D	+29.50	CD	+32.10	A
14	PEG-400 + ISO	+38.43	C	+20.97	EF	+51.52	AB	+27.07	B
15	St	+29.79	D	+45.79	A	+42.72	B	+22.16	BC
16	MMA	+25.22	D	+22.37	E	+17.10	F	+2.08	I
17	St + MMA	+5.76	G	+9.35	I	+5.70	HI	+3.29	G
18	ISO	+18.57	E	+38.20	BC	+28.61	CD	+22.23	BC

(+) means EDS whereas (-) means EDE

EDS was found the highest in the first 6 hours in V, in 24 hours St, in 48 hours (Ba+Bx) + St + MMA, in 72 hours St + MMA.

The order of convenience for groups is like (Ba+Bx) + WRM > PEG + WRM > WRM > AS, DAP, Tanalith-CBC and Vacsol. As the duration of impregnation increases, EDS increases. The order of EDS for the total duration from the highest is like (Ba+Bx) + St + MMA, PEG-400 + ISO, St, (Ba+Bx) + St, ISO, (Ba+Bx) + MMA, MMA, PEG-400 + MMA.

It is interesting that the impregnation materials can be classified in three groups for EDS (Table7).

**Table 7** Efficiency in decreasing shrinkage (EDS %)

I	II	III
(Ba+Bx)+S +MMA	St	PEG-400 + ISO
(Ba+Bx) + St	ISO	PEG-400 + MMA
(Ba+Bx) + MMA	MMA	

The order of convenience for the chemical materials and process for EDE is just the opposite of EDS.

**Effectiveness in Water Repellency**

Effectiveness in Water Repellency of test specimens calculated by the water absorption in leaching periods is given in Table 8.

EWR from the highest value is like; PEG-400+WRM>WRM>(Ba+Bx)+WRM>Commercial impregnation materials. As the

duration of leaching increases EWR decreases. The highest EWR in the first 6 hours observed at (Ba+Bx) + MMA, 24 hours (Ba+Bx) + MMA, 48 hours (Ba+Bx) + St, 72 hours (Ba+Bx) + MMA.

**Table 8** Effectiveness in water repellency EWR (%) for leaching periods

No	Impregnation Materials and Process	I (6 hours)		II (24 hours)		III (48 hours)		IV (72 hours)	
		x	HG	x	HG	x	HG	x	HG
1	Control	-		-		-		-	
2	T-CBC	42.6	D	24.0	H	20.5	GH	31.9	DE
3	AS	40.9	D	9.8	I	31.7	EF	34.6	D
4	DAP	5.3	G	11.6	I	29.3	F	26.0	E
5	V	73.2	AB	51.3	D	38.7	E	53.3	BC
6	Ba+Bx	21.8	F	25.4	GH	19.0	H	6.3	G
7	(Ba + Bx) + St	68.1	B	54.1	D	65.4	A	49.2	C
8	(Ba + Bx) + MMA	75.7	A	67.6	B	46	C	61.6	AB
9	(Ba+Bx) + St + MMA	61.8	B	39.8	F	23.3	G	32.5	D
10	PEG-400	32.6	E	29.1	G	18.3	H	15.1	F
11	PEG-400 + St	5.6	G	55.7	D	47.8	C	55.7	B
12	PEG-400 + MMA	43.8	C	60.4	C	54.6	B	66.5	A
13	PEG-400 + St + MMA	46.9	C	47.5	E	46.5	C	45.6	C
14	PEG-400 + ISO	69.6	AB	60.8	C	42.3	C	54.1	B
15	St	68.7	B	72.7	A	52.3	B	54.4	B
16	MMA	62.8	B	48.5	E	31	F	46.6	C
17	St + MMA	69.0	AB	50.7	D	51.7	B	49.9	C
18	ISO	63.8	B	23.3	H	33	EF	45.0	C

**The Effectiveness of Water Repellent Materials in Preventing Leaching**

If WRM are applied as a secondary treatment to test specimens impregnated with Ba+Bx, the amount of leached material as compared to single treatment with WRM, called

effectiveness of WRM (EWRM) is given in Table 9.

Effectiveness in preventing leaching impregnation material was found high in boron compounds than PEG-400 compounds; PEG-400 + WRM>(Ba+Bx) + WRM

**Table 9** The effectiveness of water repellent material in preventing leaching process

No	Impregnation Materials and Process	I (6 hours)		II (24 hours)		III (48 hours)		IV (72 hours)	
		x	HG	x	HG	x	HG	x	HG
I.	1 Ba + Bx + MMA	71.53	D	66.08	C	60.00	C	33.79	E
	2 (Ba + Bx)+ St	93.06	A	91.74	AB	47.69	E	66.21	D
	3 (Ba + Bx) + St + MMA	78.47	C	30.17	D	51.54	C	61.19	D
II.	4 PEG-400 + ISO	69.14	DE	69.50	BC	75.97	B	82.68	B
	5 PEG-400 + St	85.71	B	93.88	A	86.40	A	96.19	A
	6 PEG-400 + MMA	75.14	CD	76.61	B	84.17	AB	71.48	C
	7 PEG-400 + St +MMA	54.86	E	63.55	C	72.22	BC	65.36	D

The effectiveness of WRM in preventing leaching decreases in boron compounds by time but just opposite occurs in PEG-400+WRM. EWRM was found highest (Ba+Bx) + St in first 6 and 24 hours, PEG-400 + St in 48 and 72 hours. Styrene showed a leaching preventive property in all periods.

## CONCLUSION

There was no change in pH value and densities of solutions before and after the impregnation. This may be due to study with fresh solutions in each impregnation process. In the solution of T-CBC 13%, pH values being in acidic region possibly can affect the polysaccharides in wood as negative.

Regarding impregnation material groups, the order of convenience for the amount of retention is like WRM>boron compounds>commercial impregnation material>PEG-400. According to this result, the amount of retention was found highest in the groups with WRM and lowest in PEG-400. This may be due to the high concentration and low viscosity of WRM. This property is important for woods where the highest amount of retention is required for being used in open-air condition.

In commercial impregnation materials, the amount of retention was found highest in V and lowest in T-CBC.

In impregnation with boron compounds, the amount of retention was found highest in Ba+Bx+St+MMA and lowest Bx+Ba+St. The ratio of retention was found highest in Ba+Bx+St and lowest in Ba+Bx. According to this result, the impregnation of styrene with boron compounds decreased the amount of retention but increased the ratio of retention. It can be asserted that regarding the amount of retention; MMA provides more effective results with boron compounds.

In impregnation with PEG-400 groups, the amount of retention was found highest in PEG-400 + ISO and lowest in PEG-400. The ratio of retention was found highest in PEG-400 + ISO and lowest in ISO. According to this result, in secondary impregnation with WRM after PEG-400, the amount of retention increased twice. Really in Scotch pine wood, the highest amount of retention and ratio of retention was found in PEG-400 + MMA impregnation. In the impregnations with WRM, the amount of retention was found highest in styrene and lowest in MMA. The ratio of retention was found highest in styrene and lowest in ISO. According to this result, it may be said that WRM grabs the wood much more effectively. In Scotch pine wood, the highest amount retention for WRM + Polyurethane varnish was reported as 82.02 kg/m<sup>3</sup> (Yalınkılıç 1997).

Regarding the duration of leaching process, the amount of leached impregnation materials revealed lowest in first period and highest in fourth periods. While the time gets longer, the amount of leached materials increased in the specimens who are not secondary impregnated with WRM. Regarding the total amount of leached materials, the order of convenience beginning from the lowest amount is like WRM>boron compounds + WRM>Commercial Impregnation Materials>PEG-400 + WRM. According to this result, the amount of leached material becomes less in the applications with WRM. This case may be a result of hydrophobic and high grabbing property of WRM. This property can be taken into account in water soluble boron and similar compounds where the impregnation material can be leached in high humidity conditions.

The water absorption ratio observed highest in 72 hours and lowest in 6 hours. It

increased by the duration of staying in the water. Regarding the impregnation materials groups, the order of convenience for the ratio of water absorption is like WRM>P-400 + WRM>Ba+Bx + WRM > T-CBC, AS, DAP, V. According to this result, WRM and applications with WRM becomes superior over the others. This case may be a result of hydrophobic properties of WRM. The water absorption ratio was highest in Ba+Bx for 72 hours and lowest in MMA for 6 hours.

Regarding the dimensional stability, the order convenience is like WRM>boron compounds+WRM>P-400+WRM>commercial impregnation materials. According to this result, the small amount of instability in specimens impregnated with WRM groups, may due to the hydrophobic property of WRM in decreasing water absorption and preventing dimensional study. While commercial impregnation materials showed differences regarding the dimensional study, PEG-400 used solely or with WRM decreased the amount of dimensional study. Regarding time, the amount of dimensional study occurred highest in the first 6 and 24 hours. As the duration increased, the ratio of volumetric change decreased.

Regarding the efficiency increasing dimensional stability, the order of convenience is like boron compounds+WRM>PEG-400+WRM>WRM>commercial impregnation materials. Regarding hydrophobic property, the order of convenience is like PEG+WRM>WRM>Ba+Bx+WRM>commercial impregnated materials. This property is very important under high humidity and open-air conditions.

Regarding the efficiency in preventing leaching process, the order convenience is like, WRM>P-400+WRM>Ba+Bx+WRM.

The effectiveness of WRM in preventing leaching happened in (Ba+Bx)+St as 93.6% in first 6 hours, in (Ba+Bx) + St as 91.74% in 24 hours, in P-400 +St as 96.19 % in 72 hours. Related to the time, while WRM decreased the effectiveness of boron compounds in preventing leaching, just an opposite situation observed with PEG-400. Styrene proved its leaching prevention property in all periods. In the secondary impregnation of boron compounds and PEG-400 with WRM, amount of leached material, hydrophobic effectiveness, water absorption ratio, efficiency in decreasing expansion and shrinkage, efficiency in prevention of leaching were improved.

According to this result, the secondary impregnation with WRM can provide economical benefits by extending the life of wooden equipments to be used in open-air and high humidity conditions through preventing leave of impregnation substance by leaching, decreasing water absorption ratio, increasing moisture exclusion efficiency and developing dimensional stability.

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