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Impacts of impregnation with boron compounds and water repellents on the dimensional stability of scotch pine

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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 boric acid, borax, polyethyleneglychol-400, Ba+Bx, Ba+Bx+St compounds, water repellent materials; styrene, methyl methacryrilate, izocyonate and commercial impregnation materials; tanalith-CBC, ammonium sulfate, diamonium phosphate and vacsol and inspected according to ASTM D 1413-76 standards procedures. 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;
Impregnation;
Leaching;
Stability;
Scotch pine.

INTRODUCTION

Impregnation of wood with chemical materials is absolutely necessary to protect from insects, fungus etc. in many applications[1].

Boron compounds are the impregnation materials preserving wood from biotic damages but leaching from wood restricts the usage of it[2].

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[3].

The shrinkage of wood decreases by % 70 when impregnated with high concentration of salt and natural sugar solutions[4,5]. Water absorption ratio of scotch pine was found %40 when impregnated with WRF formed with % 0,5 paraffin, %10 hydrogenised resin ester and

% 9,5 white sprit[6].

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[7].

It has been reported also that impregnation with boron compounds develops some of the technological properties and additional treatment with WRM avoids leaching[8].

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.

MATERIAL AND METHOD

Material

Test specimens were prepared from Scotch pine wood obtained from Trabzon-Çaykara Forest Administration. The logs were cut according to TS 4176 standard procedures[9]. Anti blue was applied on surfaces of logs to prevent coloring after they were brought to the laboratory. Boron compounds obtained from ETIBANK-Bandyrma 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.

Method

1. Preparation of test specimens

TS 345 standard procedures were applied in the preparation of test specimens[10]. The logs are cut from a section 2m height from the bottom and under the top of main stem. Prism cut in radial direction from the sapwood, were kept in 20±2^{0}C temperature and % 65±3 relative humidity conditions up to reaching 12% humidity. The air-dry, prismatic specimens with a dimension of 2cm×2cm×50cm 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 2cm2cm×2cm.

2. 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

3. Method of impregnation

In the process of impregnation, ASTM D 1413-76 standard procedures were applied[11]. The specimens were processed with pre-vacuum of 760-mm Hg^{-1} 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^{0}C for full-dry. The full-dry, impregnated specimens were cooled in desiccators containing $CaCl_2$, for 12 hours and weighed at the analytic balance of 0,01g sensitivity. Moreover, the specimens impregnated with PEG, were kept at 60-70^{0}C temperature for 5-7 days to avoid impregnation chemicals leaking out of the wood. The retention amount R, (kg/m^3) and retention ratio R(%) were calculated by the formula[12]:

$$R = \frac{G.C}{V} \cdot 10^3 \quad R(\%) = \frac{Moes - Moeö}{Moeö} \cdot 100 \quad G = T_2 - T_1$$

T_1 : Weight of specimen before impregnation, T_2 : Weight of specimen after impregnation, V : Volume of specimen, C : Concentration of solution (%), M_{oes} : Oven dry weight of specimen after impregnation, M_{oeo} : Oven dry weight of specimen before impregnation

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

4. Leaching tests

Leaching tests were 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^{0}C. The full-dry specimens are weighed and measured in dimension. The amount of leached materials(ALM%), ratio of water absorp-

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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.	pH		Density (g/ml)		Bae (%)		°C
				Process	Process	Impreg	Impreg	1. Imp.	Bi	Ai	Bi	Ai	Bi	Ai	
I. Comp. Group	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
II. Boron Comp.	Fire preventive, insecticids, 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 4.14	7.91 4.10	1.11 0.91	1.11 0.91	62.3-	66.8-	25
		7	2	Ba+Bx 7/3 w/w	MMA	13	100	Ds	7.86 7.41	7.91 7.85	1.11 1.22	1.11 1.22	62.3-	66.8-	25
		8	2	Ba+Bx 7/3 w/w	St+MMA	13	70:30	Ds	7.86 5.70	7.91 5.73	0.91 1.12	0.91 1.12	62.3-	66.8-	25
III. PEG	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 4.14	5.60 4.10	1.12 0.91	1.12 0.91			25
		11	2	PEG-400	MMA	100	100		5.67 7.41	5.60 7.85	1.12 1.22	1.12 1.22			25
		12	2	PEG-400	St+MMA	100	70:30		5.67 5.70	5.60 5.65	1.12 1.12	1.12 1.12			25
		13	2	PEG-400	ISO	100	100		5.67 4.60	6.60 4.60	1.12 1.21	1.12 1.21			25
IV. WRM	Water repellent materials	14	1	St		100			4.14	4.10	0.91	0.91			25
		15	1	MMA		100			7.41	7.85	1.22	1.22			25
		16	1	St+MMA		70:30			5.70	5.65	1.12	1.12			25
		17	1	ISO		100			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

TABLE 2 : Retention amount of impregnation material

Grp. no	Imp. no	Chemical materials	Retention (kg/m³)			Retention Ratio % 1st impregnation			Retention Ratio % 2nd impregnation			Total retention	
			X	Ss	HG	X	Ss	HG	X	Ss	HG	X	Ss
II.	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
III.	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
IIII.	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+St+MMA	232.80	10.23	C	11.9	0.5	G	11.3	0.6	E	13.2	4.1
	13	PEG-400+ÝSO	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 devisions, HG: Homogeneous groups

tion (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:

$$ALM(\%) = \frac{Moi - Mos}{Moi} \cdot 100 \qquad RWA(\%) = \frac{Mos - Mo'}{Mo'} \cdot 100$$

$$EWR(\%) = \frac{(SAOK - SAOT)}{SAOK} \cdot 100 \qquad VCWC(\%) = \frac{Vysh - Vyöh}{Vyöh} \cdot 100$$

$$VCDC(\%) = \frac{Voi - Vos}{Voi} \cdot 100 \qquad EDE(\%) = \frac{Gk - Gt}{Gk} \cdot 100$$

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
		x	HG	Ss	x	HG	Ss	x	HG	Ss	x	HG	Ss	ALM (%)
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) + St + 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 : 17x2 = 34 group x12 specimens/group=408specimens, p=0,05)

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 : 17×2=34 group×12 specimens/group=408specimens, p≤ 0,05)

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

M_{oi}: Oven dry weight after impregnation ; M_{os}: Oven dry weight after leaching process ; M_{rs}: 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 (%); Gt : Volumetric expansion of test specimen after leaching period (%)

Data analysis

The statistical results were given by computer software, SPSS 13.0 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

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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.

Test Method to determine differences between the groups.

Results

Retention

Retention amount of impregnation material is given in TABLE 2. Retention is found the highest in WRM group and lowest in commercial impregnation materials. Order of retention amount is as WRM>PEG-400>boron compounds>Commercial impregnation materials.

The lLeached amount of impregnation material

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

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 1st period, highest in PEG-400 and lowest in St at 2nd period, highest in PEG-400 and lowest in St+MMA at 3rd period, highest in PEG-400 and the lowest in T-CBC and ISO at 4th period. According to these results, the amount of

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	HG	x	HG	x	HG	x	HG
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	CD
6	(Ba+Bx)	-32.67	C	+7.89	I	+23.74	E	-13.83	CD
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	CD
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	GH	-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 where as (-) means EDE

TABLE 7: Efficiency in decreasing shrinkage (EDS %)

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

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.

Volumetric change

Volumetric change in wet test specimens(VCWC %) and oven-dry specimens by leaching VCDC (%) is given in TABLE 5.

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.

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 (TABLE 7).

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.

TABLE 8 : Effectiveness in water repellency EWR (%) for leaching periods

No	Impregnation Materials and Process	I (6 hours) x	I (6 hours) HG	II (24 hours) x	II (24 hours) HG	III (48 hours) x	III (48 hours) HG	IV (72 hours) x	IV (72 hours) 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

TABLE 9 : The effectiveness of water repellent material in preventing leaching process

No		Impregnation materials and process	I (6 hours) x	I (6 hours) HG	II (24 hours) x	II (24 hours) HG	III (48 hours) x	III (48 hours) HG	IV (72 hours) x	IV (72 hours) HG
	1	Ba + Bx + MMA	71.53	D	66.08	C	60.00	C	33.79	E
I.	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

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, 72hours(Ba+Bx)+MMA.

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

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.

RESULTS AND DISCUSSION

There was no change in pH value and densities of solutions before and after the impregnation. This may 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 compound>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^3[12].

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 which 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 Material.

Regarding hydrophobic property, the order of convenience is like PEG+WRM>WRM> Ba+Bx+WRM> Commercial impregnated material. 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

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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.

REFERENCES

[1] L.H.Williams; Forest Product Research Society, 29-35 **(1990)**.

[2] R.J.Murphy, H.M.Barnes, S.Gray; Forest Products Research Society, 142 **(1990)**.

[3] B.A.Richardson; 'Wood preservation', Construction Press, Ltd. Lancaster, 238 **(1987)**.

[4] A.J.Stamm, L.A.Honsen; G.Ind. and Eng. Cham., **6**, 201-204 **(1935)**.

[5] A.J.Stamm; Forest Prod. Journal, **9**, 375-381 **(1959)**.

[6] E.Voulgaridis; Holz Forschung und Holz Verwertung, **6**, 141-144 **(1986)**.

[7] B.Hofors; 'The role of the wosa in the development of PEG preservation', R.M.Rowel, R.J. Barbour(Eds.); Advance in Chemistry Series, **5**: 195-217 **(1990)**.

[8] U.C.Yyldyz; Trabzon, Turkey, **1**, 403 **(1992)**.

[9] TS 4176; Ankara, Turkey, **(1984)**.

[10] TS 345; TSE Standards, Ankara, Turkey, **(1974)**.

[11] ASTM D 1413-76, 'Standard test method of testing', wood preservatives by laboratory, Sorlblock Cultures, Annual Book of ASTM Standards, USA, 452-460 **(1976)**.

[12] H.Keskin, M.Atar, H.G.Yavuzcan; Journal of Applied Polymer Science, **93(2)**, 498-504 **(2004)**.