Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 9 (22): 4066-4070, 2009
ISSN 1812-5654

Surface Adhesion Strength of Varnishes in Some Impregnated Woods

[1]M. Atar and [2]M.H. Çolakoğlu
[1]Department of Furniture and Decoration, Faculty of Technical Education, Gazi University, 06500 Besevler, Ankara, Turkey
[2]Kosgeb, Small and Medium Industry Development Organization, 06570 Ankara, Turkey

Abstract: This study was performed to determine the impact of impregnation chemicals on the surface adhesion strength of varnishes in some woods. For this purpose, Scotch pine, Oriental spruce and Uludağ fir woods were used according to ASTM 358. Test samples were impregnated with boric acid (Ba) and borax (Bx) by vacuum technique according to ASTM D 1413. After impregnation process cellulosic (Cv), synthetic (Sn), polyurethane (Pu), waterborne (Wb), acrylic (Ac) and acid hardening (Ah) varnishes were applied on the surface of test samples according to ASTM D 3023. Adhesion strength test was conducted on the test specimens after varnishing process was determined according to ASTM D 4541. According to the test results, the highest adhesion strength was obtained in Scotch pine impregnated with borax and varnished with acrylic varnish, and the lowest was obtained in Uludağ fir impregnated with boric acid and varnished with cellulosic varnish. As a consequence, Scotch pine+Borax+Acrylic varnish combination is recommended for usage in usage areas having a high risk of varnish abrasion resistance.

Key words: Surface adhesion strength, impregnation, boron compounds, varnishes, softwoods

INTRODUCTION

Preserving wood material from environmental effects to provide a long usage period is economically important. Preserving and beautifying covering materials like paint, polish and varnish are used for this reason. Technical surface processes also increase economic, esthetic and economic value of wood.

Furniture coated only with paint and varnish has surface protection only for two years. So, after the impregnation with materials having appropriate water-repellent, biotic and abiotic effects, varnishing and painting applications are important for long term utilization against photochemical degradation, dimensional changes, biological factors and fire.

In painting and varnishing applications with water-repellent materials, wood materials impregnated with boron are more resistant to environmental conditions. Solution of copper, chrome and salt on the surface of wood material impregnated with copper, chrome and boron make wood material more resistant to environmental effects.

Processes like bleaching and impregnation affect the wood structure and develope the specifications such as hardness, color, brightness and surface adhesion strength to some extent. The surface adhesion strength is one of the most important parameters for limiting the usage of varnishes. Adhesion is determinative in this sense (Atar *et al.*, 2004).

For Scotch pine (*Pinus silvestris* Lipsky), surface adhesion strength of varnishes was decreased after lightening the color (Özçifçi *et al.*, 1997). For chestnut (*Ulmus camppestris* Spach.), adhesion strength of polyurathane and polyester varnishes was decreased after lightening the color (Sönmez *et al.*, 2002).

The aim of this study was to determine the effects of some boron compounds on the surface adhesion strength for some varnishes in Scotch pine, Oriental spruce and Uludağ fir woods.

MATERIALS AND METHODS

Wood materials: Scotch pine (*Pinus sylvestris* L.), Oriental spruce (*Picea orientalis* Lipsky) and Uludag fir (*Abies Bornmülleriana* Lipsky) woods were chosen randomly from timber merchants of Ankara, Turkey. Special emphasis is given to the selection of the wood materials. Accordingly, non-deficient, proper, knotless, normally grown (without zone line, without reaction wood and without decay, insect mushroom damages) wood materials were selected according to TS 2470 (1976).

Varnishes: Cellulosic (Cv), synthetic (Sn), polyurethane (Pu), waterborne (Wb), acrylic (Ac) and acid hardening (Ah)varnishes were applied on the test samples according to the producers definition. Amount of varnish was determined according to the amount of solid

Corresponding Author: M. Atar, Department of Furniture and Decoration, Gazi University, Faculty of Technical Education, 06500 Besevler, Ankara, Turkey

Table 1: Some properties of varnishes

Type of varnish	pH value	Density (g cm^{-3})	Viscosity (snDIN Cup/4 mm)	Amount applied (g m^{-2})	Nozzle gap (mm)	Air pressure (bar)
Polyurethane (filler)	5.94	0.98	18	125	1.8	2
Polyurethane (finishing)	4.01	0.99	18	125	1.8	2
Synthetic	-	0.94	18	100	-	-
Wb (primer)*	9.17	1.014	18	100	1.3	1
Wb (filler)**	9.30	1.015	18	67	1.3	1
Wb (finishing)***	8.71	1.031	18	67	1.3	1
Cv (Cv)	2.90	0.955	20	125	1.8	3
Cv (finishing)	3.40	0.99	20	125	1.8	3
Ac (filler)	4.30	0.95	18	125	1.8	2
Ac (finishing)	4.60	0.97	18	125	1.8	2
Ah (finishing)	8.00	0.99	18	100	1.8	3

*ASTM D 17, **ASTM D 65, ***ASTM D 45

material by the producer's definition. Technical specifications of varnishes are given in Table 1.

Impregnation chemicals: Boric acid and borax are obtained from Etibank-Bandýrma (Turkey) Borax Factory. Properties of Boric acid (H_3BO_3) is 56.30 ½ % B_2O_3 43.70% H_2O with a molecular weight 61.8, 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 1.82 g cm^{-3}, melting point 741°C (Örs *et al.*, 2006).

Preparation of test samples: The rough drafts for the preparation of test and control specimens were cut from the sapwood parts of massive woods with a dimension of 190x140x15 mm and conditioned at 20±2°C temperature and 65±3% relative humidity. The specimens were kept until reaching to Relative Humidity (RH) according to ASTM D 358 (1983). The air-dry specimens with a dimension of 150x100x10 mm were cut from the drafts for impregnation and varnishing. The test specimens were impregnated with 5.5% boric acid and 5% borax according to ASTM D 1413 (2005). Accordingly, the samples were exposed to 700 mm Hg^{-1} prevacuum for 60 min, and then held in a solution normal atmospheric pressure for 60 min to allow the diffusion of the impregnation material (Keskin, 2007). The processes were carried out at 20±2°C. Retention of impregnation material (R) was calculated by the following equation:

$$R = \frac{G.C}{V} 10\,kg\,m^{-3} \qquad (G = T_2 - T_1)$$

where, G is the amount of impregnation solution absorbed by the specimen, T_2 is the specimen weight after the impregnation, T_1 is the specimen weight before the impregnation, C is the concentration (%) of the impregnation solution and V is the volume of the specimens. Impregnated test specimens were kept under 20±2°C temperature and 65±3% relative humidity until reaching to a stable weight.

Varnishing: First, test specimens were varnished according to ASTM D-3023 (1998). Second, the surfaces of specimens were sanded with abrasive papers to remove the fiber swellings and dusts were leaned before varnishing. Producer's definition was taken into care for the composition of solvent and hardener ratio and one or two finishing layers were applied after the filling layer. Finally, spray nozzle distance and pressure were adjusted according to the producer's definition and moved in parallel to the specimen surface at a distance of 20 cm. Varnishing be done under 20±2°C temperature and percentage 65±3% relative humidity conditions. Varnish layer thickness were found 78 µm in cellulosic varnish, 92 µm in synthetic varnish, 120 µm in polyurethane varnish, 66 µm in water-borne varnish, 128 µm in acrylic varnish and 100 µm in acid hardening varnish. The difference among the varnishes might be due to different solid materials.

Adhesion strength tests: Adhesion strength measurements were applied according to ASTM D 4541 (1995) with adhesion test device working with pneumatic system. Surfaces of test specimens were coated with protective layer and fully dried. Test cylinders with ⌀ 20 mm were adhered to these surfaces by using mold under normal room temperature. Two hours later, gelled adhesive residues were removed by a spatula and left for drying for 24 h. Before tests, samples were conditioned at 23±2°C and 50±5% relative humidity for 24 h according to TS EN 24624 (1996). Later on, varnish layer was cut by a cutter till the wood material surface. In pneumatic adhesion device with two bar pressure, samples were pulled off from cylinders adhered to surface. Pulling process were completed in 90 sec. Adhesion strength ($\sigma_ç$) was calculated by the following equation:

$$\sigma_ç = \frac{4F}{\pi.d^2}\,MPa$$

where, F is the maximum force in Newton and d is diameter of test cylinder in mm.

Data analysis: By using 3 different types of wood, 2 types of impregnation+1 control specimen, 6 different types of varnish, as a total of 270 specimens (3×3×6×5 = 270) were prepared with 5 specimens for each parameter. Multiple variance analysis was used to determine the differences in adhesion strength values of specimens. Duncan Test was used to determine the significant difference between the groups.

RESULTS AND DISCUSSION

Retention: Retention amounts according to wood and impregnation material is given in Table 2. Amounts of retention were found different depending on wood type and impregnation materials. Retention amount of impregnation materials was the highest in pine+boric acid and the lowest in spruce+borax. Reason of higher amount of retention with boric acid might be due to high concentration of solution. This provides advantages for applications requiring high retention quantity. On the other hand, retention was found higher in pine than spruce and fir. This case may be due to pit aspiration of spruce and fir woods.

Table 2: Retention amounts according to wood and impregnation material (kg m^{-3})

Type of process	x	HG*
Scotch pine+Ba	16.90	A
Uludag fir+Ba	13.00	B
Uludag fir+Bx	12.72	B
Scotch pine+Bx	9.103	C
Oriental spruce+Ba	4.979	D
Oriental spruce+Bx	4.227	E

*LSD: 2.012, HG: Degree of homogeny, x: Means

Table 3: Surface adhesion strength average values (MPa)

Type of wood material	x	HG*
Scotch pine (I)	3.078	A
Oriental spruce (II)	2.587	B
Uludag fir (III)	0.373	C
Impregnation chemicals	x	HG**
Control(C)	2.756	A
Boric Acid (Ba)	2.574	B
Borax (Bx)	2.707	A
Varnishes	x	HG***
Cellulosic varnish (Cv)	2.244	E
Synthetic varnish (Sv)	2.491	CD
Polyurethane varnish (Pu)	2.420	D
Water-borne varnish (Wb)	2.604	C
Acrylic varnish (Ac)	3.016	B
Acid hardening varnish (Ah)	3.299	A

*Different letters in the columns refer to significant changes among types of wood materials at 0.05 confidence level ($LSD_{0.5}$ = 0.1021). **Different letters in the columns refer to significant changes among impregnation materials at 0.05 confidence level ($LSD_{0.5}$ = 0.1444). ***Different letters in the columns refer to significant changes among varnishes at 0.05 confidence level ($LSD_{0.5}$= 1.236). I: Scotch pine, II: Oriental spruce, III: Uludag fir, C: Unimpregnated samples, Ba: Boric acid, Bx: Borax, Cv: Cellulosic, Sn: Synthetic, Pu: Polyurethane, Wb: Waterborne, Ac: Acrylic, Ah: Acid hardening

Adhesion strength: Adhesion strength average values according to wood material type, varnish type and impregnation material are given in Table 3.

Adhesion strength was the highest in pine and the lowest in fir. According to varnish type, adhesion strength was the highest in acid hardening varnish, the lowest in cellulosic varnish. Adhesion strength was the highest in boric acid according to impregnation material type. Adhesion strength was lower in impregnated samples. Accordingly, impregnation materials have decreasing effect for adhesion strength of varnishes. Average values according to wood material type+ impregnation material, impregnation material+varnish type and wood material type+varnish type are given in Table 4.

Adhesion strength value for wood material type+ impregnation material was the highest in pine+borax and the lowest in fir+borax. For impregnation material+varnish type, adhesion strength was the highest in boric acid+ acid hardening varnish, the lowest in boric acid+cellulosic varnish. Impregnation materials have increasing impact for adhesion strength of water-based and cellulosic varnishes and decreasing impact for other types of varnishes. Results of multiple variance analysis

Table 4: Surface adhesion strength average values according to wood, impregnation material and varnish type (MPa)

Types of material	x	HG
Wood materials+impregnation*		
I	3.063	B
I+Ba	2.887	B
I+Bx	3.283	A
II	2.630	C
II+Ba	2.557	C
II+Bx	2.573	C
III	2.574	C
III+Ba	2.280	D
III+Bx	2.265	D
Impregnation+varnishes**		
Cv	2.180	E
Ba+Cv	2.267	DE
Bx+Cv	2.287	DE
Sn	2.667	BC
Ba+Sn	2.373	DE
Bx+Sn	2.433	CDE
Pu	2.553	BCD
Ba+Pu	2.427	CDE
Bx+Pu	2.280	DE
Wb	2.513	BCD
Ba+Wb	2.560	BCD
Bx+Wb	2.740	B
Ac	3.307	A
Ba+Ac	2.527	BCD
Bx+Ac	3.213	A
Ah	3.313	A
Ba+Ah	3.293	A
Bx+Ah	3.289	A

*Different letters in the columns refer to significant changes among wood and impregnation materials types at 0.05 confidence level ($LSD_{0.5}$ = 0.2725). **Different letters in the columns refer to significant changes among impregnation materials and varnish types at 0.05 confidence level ($LSD_{0.5}$ = 0.4719). I: Scotch pine, II: Oriental spruce, III: Uludag fir, Co: unimpregnated samples, Ba: boric acid, Bx: borax, Cv: Cellulosic, Sn: synthetic, Pu: Polyurethane, Wb: Waterborne, Ac: Acrylic, Ah: Acid hardening

Table 5: Multiple variance analysis for impact of wood, varnish and impregnation material for surface adhesion strength

Factors	Degrees of freedom	Sum of squares	Mean square	F-value	Probably %5 (Sig.)
Factor A	2	23.519	11.759	96.8603	0.0000
Factor B	5	35.738	7.148	58.8740	0.0000
Wood and varnish	10	13.102	1.310	10.7916	0.0000
Factor C	2	1.584	0.792	6.5235	0.0018
Wood and impregnation	4	2.694	0.673	5.5471	0.0003
Varnish and impregnation	10	5.678	0.568	4.6768	0.0000
Wood varnish and impregnation	20	8.353	0.418	3.4401	0.0000
Error	216	26.224	0.121		
Total	269	116.891			

Factor A: Wood type (Scotch pine, Oriental spruce, Uludag fir) Factor B: Varnish type (Cv: Cellulosic, Sn: Synthetic, Pu: Polyurethane, Wb: Waterborne, Ac: Acrylic, Ah: Acid hardening) Factor C: Impregnation chemicals (Ba: Boric acid, Bx: Borax)

Table 6: Duncan test results

Process type	x	HG[a]	Process type	x	HG[a]	Process type	x	HG[a]
I+Bx+Ac	4.16	A	I+Ba+Pu	2.94	E-J	III+Ba+Wb	2.34	K-P
I+Ac	3.68	B	I+Bx+Cv	2.92	E-J	III+Pu	2.32	K-Q
III+Ba+Ah	3.64	BC	I+Pu	2.84	F-K	II+ Wb	2.32	K-Q
II+Bx+Ah	3.64	BC	I+Bx+Sn	2.84	F-K	II+Ba+Sn	2.30	L-Q
III+Ah	3.52	B-D	III+Bx+Ah	2.82	F-L	II+Bx+Sn	2.28	M-Q
I+ Wb	3.40	B-E	III+Sn	2.70	G-M	II+Bx+Pu	2.28	M-Q
I+Bx+Ah	3.40	B-E	II+Ba+Ac	2.68	G-M	III+Bx+Cv	2.28	M-Q
I+Ah	3.28	B-F	II+Sn	2.66	H-M	III+Ba+Sn	2.24	M-Q
II+Ba+Ah	3.28	B-F	I+Ba+Cv	2.66	H-M	II+Ba+Cv	2.18	M-R
II+Ac	3.24	B-F	I+Sn	2.64	H-M	III+Bx+Sn	2.18	M-R
I+Bx+Pu	3.24	B-F	II+Bx+ Wb	2.64	H-M	III+Cv	2.08	N-S
I+Ba+Ac	3.20	B-G	I+Ba+Sn	2.58	I-N	III+Ba+Cv	1.96	O-S
II+Ah	3.14	C-H	I+Cv	2.54	I-N	II+Cv	1.92	O-S
I+Bx+ Wb	3.14	C-H	II+Ba+Pu	2.54	I-N	III+ Wb	1.82	P-S
III+Ac	3.00	D-I	III+Bx+Ac	2.54	I-N	III+Ba+Pu	1.80	Q-S
I+Ba+ Wb	2.98	E-I	II+Pu	2.50	I-N	III+Ba+Ac	1.70	R-T
I+Ba+Ah	2.96	E-J	III+Bx+Wb	2.44	J-O	II+Bx+Cv	1.66	ST
II+Bx+Ac	2.94	E-J	II+Ba+ Wb	2.36	K-O	III+Bx+Pu	1.32	T

HG = Degree of Homogeny, x = Means, (a) Different letters in a column refers to significant differences among the different interactions of wood, varnishes and impregnation materials at 0.05 confidence level ($LSD_{0.5}$: 3.708), I: Scotch pine, II: Oriental spruce, III: Uludag fir, Ba: Boric acid, Bx: Borax, Cv: Cellulosic, Sn: Synthetic, Pu: Polyurethane, Wb: Waterborne, Ac: Acrylic, Ah: Acid hardening

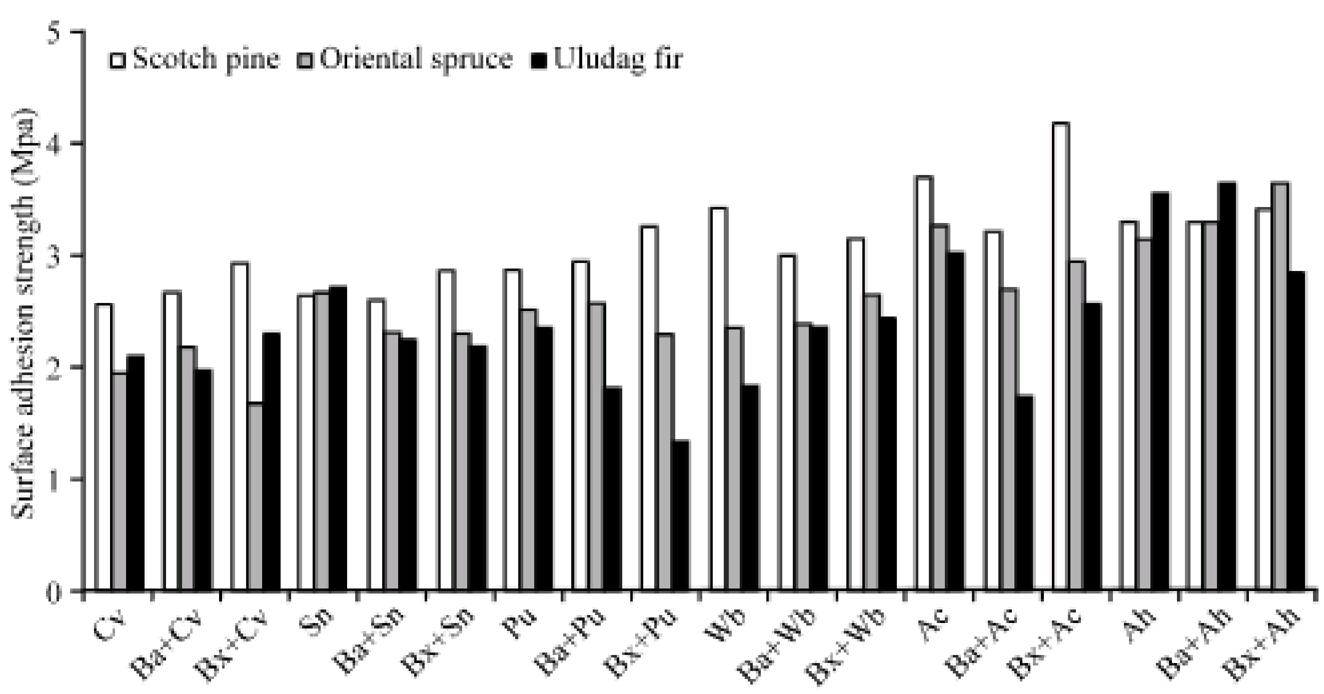

Fig. 1: Surface adhesion strength value changes in varnished surfaces

for impact of wood+varnish type+impregnation material for surface adhesion strength is given in Table 5.

Impact of wood material type, impregnation material and varnish type on adhesion strength have been found important for the effect of variance sources on the adhesion strength (α = 0.05). Duncan Test results are given in Table 6 to indicate the importance of differences between the groups.

Adhesion strength value was the highest in pine+acrylic varnish and the lowest in spruce+cellulosic varnish for varnished wood material without impregnation. For samples varnished after impregnation, adhesion strength as the highest in pine varnished with acrylic after impregnation with borax and the lowest in fir varnished with polyurethane varnish after impregnation with borax (Fig. 1).

CONCLUSIONS

Adhesion strength value was the highest in pine, borax and acid hardening varnish and the lowest in fir, boric acid and cellulosic varnish. In Scotch pine, adhesion strength was found 19% higher than Oriental spruce and 30% higher than Uludağ fir.

Adhesion strength value in impregnation treatment was 7% lower in boric acid, 2% lower in borax than control specimen. Accordingly, impregnation materials have decreasing effect on adhesion strength values. This case might be due to decreasing of adhesion strength between wood material and varnish layer because of impregnation material. After treating of Scotch pine with different bleaching and impregnation materials, adhesion strength of some varnishes decreased. In this regard, impregnation with boron compounds provides an advantage for applications in usage areas where adhesion strength is important.

Adhesion strength for wood material+impregnation material was the highest in Scotch pine+Bx (3.283) and the lowest in Uludað fir+Bx (2.265). Impregnation materials showed an increasing impact for the adhesion strength of Scotch pine, Oriental spruce and Uludað fir at a rate of 4, 3 and 11% in boric acid and 7, 2 and 12% decrease in borax, respectively.

Adhesion strength value according to impregnation material+varnish type combination was the highest in Ba+acid hardening (3.293) and the lowest in Bx+polyurethane (2.280). Adhesion strength value of varnished samples, which were not impregnated, was different from impregnated and varnished samples. Impregnation materials showed increasing effect in the adhesion strength of cellulosic and water-borne varnishes at a rate of 4 and 2% for boric acid, 5% and 8% for borax. Impregnation materials showed decreasing effect for synthetic, polyurethane, acrylic and acid hardening at a rate of 12, 5, 25 and 1% in boric acid and 9, 11, 3 and 1% in borax orderly. Adhesion strength value was the lowest in synthetic varnish. Accordingly, boron compounds have different effects for adhesion strength of varnishes.

Adhesion strength according to wood material+ impregnation material+ varnish combination was the highest in I + Bx + Ac (4.160) and the lowest in III + Bx + Pu (1.320). For surface adhesion strength of varnishes, impregnation material and varnish type was effective in addition to wood material type, but impregnation material and varnish type were the main sources of this effect. Adhesion resistance is an important property for many varnish items, e.g., pavement, flooring parts of machines, etc. Decreasing of adhesion resistance is caused by various factors; walking, friction, blows, oscillations, the influence of sand, dirt and other extraneous bodies and by chemicals, moisture, and change in temperatures. As a result, boron compounds showed the positive effect on the surface adhesion strength for varnishes. Accordingly, Scotch pine + Borax + Acrylic varnish are recommended for the usage areas having a high risk of varnish abrasion resistance.

ACKNOWLEDGMENT

This study was supported by TUBITAK. The Scientific and Technological Research Council of Turkey (Project code: MISAG-237).

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