Impacts of Impregnation with Boron Compounds on Surface Roughness of Woods and Varnished Surfaces

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ABSTRACT: This study determines the effects of the process of impregnation of boron compounds on the surface roughness of Oriental beech, Scotch pine, Oriental spruce, and Uludağ fir woods and varnished surfaces. For this purpose, samples are prepared according to ASTM D 358 and impregnated according to ASTM D 1413-99 with a 5.5% solution of boric acid (Ba), borax (Bx), and Ba with Bx (Ba + Bx) and varnished with synthetic varnish (Sv) and water-based varnish (Wb) in accordance with ASTM D 3023. The surface roughness is determined according to ISO 4287 and TS 930 standards. The results indicate that the surface roughness is the highest in Uludağ fir, Wb, and Bx and the lowest in Oriental spruce, Sv, and Ba + Bx. For the combination of wood, impregnation material, and varnish, the surface roughness is the highest in Oriental beech with Bx and Wb and the lowest in Scotch pine with Ba + Bx and Sv. The surface roughness is less in impregnated samples than unimpregnated samples and in impregnated and varnished samples than impregnated and unvarnished samples. According to these results, boron compounds decrease the surface roughness of varnishes and wood materials. Thus, impregnation of wood with boron compounds decreases the surface roughness. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 102: 4952–4957, 2006

Key words: coatings; surface roughness; compounding; density; impregnation

INTRODUCTION

Wood materials are impregnated with chemicals to increase durability against biotic and abiotic damage and to elongate economic life. Varnishing increases the esthetic and economic value of wood and keeps it free from dirt and stain.

Wood material, which has an important empty space because of its porous structure, gains irregularities on the surface when processed by cutting.[1] Material structure and manufacturing techniques create surface roughness directly, affecting the surface finishing process. If the surface process is not sufficient, after painting and varnishing, the surface roughness becomes much more evident and causes a decrease in quality.[2]

Scotch pine impregnated with different solutions of chromated copper arsenate (Tanalith-E, Wolmanith-CX, or ACQ) and left under open air conditions had less surface roughness than other unimpregnated samples.[3]

It was reported that the surface roughness in wood increases with humidity.[4] In maple, Douglas fir, and poplar woods, the surface roughness is increased by the depth and rate of cut and the dimensions of abrasive grains.[5]

Wood samples were cut in the radial and tangential directions from Oriental beech, oak, Scotch pine, and Uludağ fir. They were processed with a radial saw, planer and sanded with number 80 abrasive paper. The surface roughness (R_a) values were 5.20 μm in Scotch pine, 7.32 μm in Uludağ fir, 7.78 μm in Oriental beech, and 11.84 μm in oak.[6]

Locust, pear, chestnut, Toros cedar, and oak wood samples were sanded with number 120 abrasive paper to attain a smooth surface and than sanded with number 80 abrasives.[7] The R_a values of parquets were measured and found to be 4.50 μm in Oriental beech and 5.12 μm in oak.[8] They were decreased in Oriental beech, Scotch pine, Oriental spruce, and Uludağ fir by vacuum impregnation with 5.5% solutions of boric acid (Ba), borax (Bx), and Ba with Bx (Ba + Bx).[9]

This research was performed in order to determine the effects of the impregnation process on the surface roughness of Oriental beech, Scotch pine, Oriental spruce, and Uludağ fir woods and varnished surfaces.

EXPERIMENTAL

Wood materials

Oriental beech (*Fagus orientalis* Lipsky), Scotch pine (*Pinus sylvestris* Lipsky), Oriental spruce (*Picea orientalis* Lipsky), and Uludağ fir (*Abies bornmülleriana* Lipsky) woods were selected as test materials because of their

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wide use in industry. Wood samples were selected randomly from timber merchants in Ankara, Turkey. Special emphasis was given for the selection of wood materials. Accordingly, nondeficient, proper, knotless, normally grown (without zone line, reaction wood, decay, or mushroom damage) wood materials were selected.

Impregnation material

The Ba and Bx impregnation materials were obtained from Etibank–Bandırma Borax and Acid Factory. The Ba (H_3BO_3) contained 56.30% $0.5B_2O_3$ and 43.7% H_2O with a molecular weight of 61.84, a density of 1.4 g cm^{-3}, and a melting point of 171°C. The Bx ($Na_2B_4O_7$ $5H_2O$) contained 21.28% Na_2O, 47% B_2O_3, and 30.9% H_2O with a molecular weight of 291.3, a density of 1.8 g cm^{-3}, and a melting point of 741°C.[10]

Varnishes

Synthetic varnish (Sv) creates irreversible and bright layers by reaction, oxidation, and vaporization of solvents. It is durable for water and humidity and has a low hardness value. Because of its property of durability to humid conditions, it is preferred in the production of furniture and decorations that will be used in open air, high humidity, and water contact conditions but with low resistance.

Water-based varnish (Wb) is a colorless and odorless varnish that does not turn yellow with time and does not cause any changes in the properties of wood materials. It dries chemically and forms hard layers, can be applied several times on the same day, and is resistant to acidic foods such as mustard and vinegar. The layer thickness should be between 70 and 80 μm in wet conditions and 25 and 35 μm in dry conditions. It is a milky liquid and has a density of 1.00 ± 0.05 g cm^{-3} at 20°C.

The surfaces on which Wb is applied should be dry and cleaned of dust, dirt, and oily stains by sandpapering. It should be applied in one to three layers for nontreated surfaces and one to two layers for previously painted surfaces. It takes about 30 min for the first layer to have touch resistance. For multilayer applications, the subsequent layers should be allowed to dry approximately 4–6 h. One liter of varnish is reported to be sufficient to treat a 10-m^2 surface.[11]

In this study Jansen Wb, which is a single compound polyurethane–acrylic resin produced according to DIN 53160, was applied in accordance with ASTM D 3023. During varnish preparation and to avoid the inferior effects on the layer performance, emulsion ratios were carefully calculated considering the product specifications. The varnish viscosity was determined as 18 s/4-mm diameter flow-cup at 20 ± 2°C and 65 ± 3% relative humidity (RH). It was applied on the surface of test samples by means of hard-haired brushes. The solid content and dry film thickness of Wb were determined to be 28% and 24 μm, respectively.[12]

Some of the technological properties of different kinds of varnishes used in the tests are given in Table I.

Preparation of test samples

The wood samples cut in rough dimensions were conditioned at 20 ± 2°C and 65 ± 3% RH until reaching to 12% dry-air moisture content. The humidity was determined in accordance with the TS 2471 standard.[13] Test samples were cut from sapwood with dimensions of $10 \times 100 \times 150$ mm.

In the process of impregnation, ASTM D 1413-99 standard procedures were applied.[14] Accordingly, the test samples were processed with a prevacuum of 60 cm Hg^{-1} for 60 min and then atmospheric pressure for 60 min.

Impregnated samples were stored under air circulation until reaching dry-air moisture content (12%). Samples were later weighed with an analytic balance with 0.001-g sensitivity. The amount of retention (R) is calculated by the formula

$$R = \frac{G \times C}{V} 10^3 \text{ kg m}^{-1} \quad G = T_2 - T_1$$

where T_1 is the sample weight after impregnation, T_2 is the sample weight before impregnation, V is the volume of the sample, and C is the concentration of the solution (%).

In the process of varnishing, ASTM D 3023 standard procedures were applied.[15] According to this standard, the surfaces were sanded slightly to remove fiber swells, cleaned of dust, and varnished according to the definition of the producer. According to this, surfaces

TABLE I
Properties of Varnishes Used in Tests

Type of varnish	pH	Density (g cm^{-3})	Viscosity (Pa S)	Amount used (g m^{-2})
Synthetic	—	0.94	5000 – 6000	120
Water based				
ST D17 (primer)	9.17	1.014	5000 – 6000	160
AST D65 (filling)	9.30	1.015	5000 – 6000	67
AST D45 (last)	8.71	1.031	5000 – 6000	67

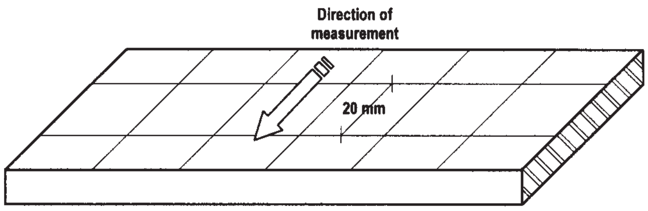

Figure 1 The test sample.

of samples are coated with 120 g m^{-2} Sv and 160 g m^{-2} Wb varnish.

Test methods

The surface roughness was determined in accordance with the ISO 4287 standard.[16] TIME TR-200 contact-type test equipment, which measures the sequential profile change property, was used in the measurements according TS 971,[17] TS 930,[18] and TS 6959 standards.[19] The sensitivity of TIME TR-200 is 0.01–0.04 μm and the lengths of the measurements were 0.25, 0.8, and 2.5 mm. The temperature was 0–40°C and the RH was <90% in the measurement conditions.

Measurements were taken at five different points and perpendicular (⊥μm) to the fiber as shown in Figure 1. The test equipment was adjusted for a 2.5-mm length of one stride and three measurements. Test specimens and the measuring instrument were placed parallel to the ground and the needle was placed at the region in between the 20-mm parallel lines. Measurements were made of the surface roughness.

Data analyses

Forty-eight (4 × 3 × 2 × 2) test samples were prepared for four different type of woods, three impregnation materials, two types of varnishes, and two for each measurement. In each test specimen seven measurements were made (48 × 7 = 336). A multiple analysis of variance method was used to determine the difference between the groups of test samples. The Duncan test was applied to significantly evaluate the differences between the groups.

RESULTS AND DISCUSSION

The amounts of retention of impregnation materials are given in Table II. The highest retention amount was obtained in Oriental beech impregnated with Ba, and the lowest was obtained in Oriental spruce impregnated with Bx. The resin in Scotch pine and pit aspiration in Uludağ fir may have affected the results.

Table III provides the R_a values for the types of processes, and Table IV gives the type of wood plus impregnation material and impregnation material plus varnish interactions. Multiple analyses of variance are given in Table V for the impact of the type of wood, impregnation material, and varnish on the surface roughness.

The highest R_a was measured in Uludağ fir and Oriental beech impregnated with Bx and coated with Wb. The value was higher in Oriental beech than in Scotch pine and Oriental spruce. This may be because of the thick and multiseriate rays in Oriental beech wood. In Uludağ fir, fast growing and wide annual rings may be the reason. Wide lumen and annual rings, thick rays, and defects in wood cause increasing surface roughness.[20] The R_a was the highest in the control samples. According to this result, impregnation and varnishing develops the surface quality.

The highest value for the mean surface roughness was found in Uludağ fir impregnated with Bx and the lowest value was in synthetically varnished Scotch pine impregnated with Ba + Bx. The impact of the type of wood, impregnation material, and varnish on the surface roughness was statistically important ($p < 0.05$). To determine the differences between the groups, the Duncan test results are given in Table VI.

The retention of the impregnation material on R_a was not affective but the type of wood, impregnation material, and varnish was affective. Thus, impregnat-

TABLE II
Mean Amount of Retention (kg m^{-3})

Wood materials	Ba	Bx	Ba + Bx
Oriental beech	13.15	9.32	10.24
Scotch pine	2.86	2.41	5.42
Oriental spruce	4.59	2.03	3.67
Uludağ fir	5.48	2.73	4.65

Ba, boric acid; Bx, borax.

TABLE III
Surface Roughness for Type of Process (⊥μm)^{R_a}

Types of materials	R_a (⊥μm)	HG
Wood[a]		
I	2.759	A
II	2.406	B
III	2.204	C
IV	2.824	A
Impregnation[b]		
1	3.280	A
2	2.240	C
3	2.564	B
4	2.109	D
Varnishes[c]		
Uv	4.184	A
Wb	2.479	B
Sv	0.987	C

* HG, different letters in the columns refer to significant changes among wood type, impregnation, and varnishes at 0.05 confidence level (a: $LSD_{0.5}$ = 0.1218; b: $LSD_{0.5}$ = 0.1218; c: $LSD_{0.5}$ = 0.1055). ⊥, perpendicular +D the fiber; A, the highest value; D, the lowest value; I, Oriental beech; II, Scotch pine; III, Oriental spruce; IV, Uludağ fir; 1, unimpregnated; 2, boric acid; 3, borax; 4, Ba + Bx; Uv, unvarnished; Wb, water-based; Sv, synthetic-based.

TABLE IV
Surface Roughness for Different Types of Wood, Varnish, and Impregnation Material Combinations (⊥µm)^{R_a}

Type of wood	Stat. values	Type of process											
		C	Ba	Bx	Ba + Bx	C + Wb	Ba + Wb	Bx + Wb	Ba + Bx + Wb	C + Sv	Ba + Sv	Bx + Sv	Ba + Bx + Sv
I	x	5.573	3.924	4.338	3.8284	3.6804	1.835	2.9644	1.9984	1.7065	1.0438	1.1968	0.7757
	v	0.2353	0.3378	0.2610	0.1728	0.0831	0.1314	0.2395	0.1829	0.0280	0.1961	0.0461	0.0351
	Ss	0.5046	0.5846	0.5633	0.4745	0.4456	0.3687	0.4907	0.5473	0.2051	0.4717	0.2158	0.2368
	Max	6.448	4.571	5.377	4.463	4.392	2.394	3.623	2.398	1.915	1.475	1.598	1.015
	Min	5.143	3.082	3.845	3.294	3.537	1.419	2.252	1.164	1.489	0.196	0.965	0.426
II	x	4.1653	3.5331	3.8621	3.5172	3.292	2.8642	2.3068	1.973	1.3042	0.6024	0.9621	0.480
	v	0.2116	0.1180	0.0472	0.0311	0.1518	0.2842	0.5011	0.1702	0.0389	0.0321	0.0223	0.0267
	Ss	0.4701	0.4195	0.2420	0.2141	0.3941	0.6246	0.7097	0.4409	0.2282	0.1802	0.1715	0.1704
	Max	5.059	4.063	4.185	3.768	4.015	3.711	3.382	2.583	1.581	0.895	1.209	0.655
	Min	3.656	3.147	3.505	3.324	2.893	2.289	1.276	1.474	0.917	0.44	0.736	0.22
III	x	4.276	3.903	3.654	3.6163	2.810	1.4150	1.845	1.253	1.363	0.7318	1.0528	0.526
	v	0.0644	0.11974	0.2041	0.1117	0.0448	0.2707	0.1603	0.0492	0.0089	0.0148	0.0024	0.0071
	Ss	0.3238	0.35472	0.5078	0.3855	0.2148	0.5856	0.5221	0.2219	0.0985	0.1432	0.0569	0.0847
	Max	4.816	4.402	4.262	3.957	3.115	2.656	2.375	1.66	1.586	0.96	1.146	0.659
	Min	4.021	3.302	3.12	2.918	2.5	1.068	1.143	1.02	1.278	0.608	1.013	0.438
IV	x	5.692	3.936	4.820	4.1956	3.5742	2.4485	2.8927	2.2952	1.682	0.6387	0.879	0.8475
	v	0.3144	0.0196	0.0152	0.1255	0.6316	0.0632	0.1013	0.1115	0.0320	0.0006	0.0120	0.0389
	Ss	0.5849	0.1747	0.1476	0.3826	0.8584	0.2716	0.3437	0.3607	0.1933	0.0267	0.1184	0.2132
	Max	6.733	4.124	5.012	4.684	4.925	2.667	3.08	2.697	1.632	0.669	0.978	1.156
	Min	4.993	3.688	4.706	3.699	2.306	2.332	2.345	1.636	1.483	0.609	0.708	0.548

I, Oriental beech; II, Scotch pine; III, Oriental spruce; IV, Uludağ fir; c, control; x, mean; v, varance, Ss, standard deviation; max, maximum; min, minimum.

TABLE V
Results of Variance Analysis of Impact of Types of Wood, Varnish, and Impregnation Material Combinations on Surface Roughness

Source of variance	Degrees of freedom	Sum of squares	Ave. of squares	*F* value	$p < 0.05$ signif.
Factor A	3	21.760	7.253	45.1396	0.0000
Factor B	2	570.744	285.372	1775.9606	0.0000
AB	6	11.858	1.976	12.2996	0.0000
Factor C	3	69.123	23.041	143.3908	0.0000
AC	9	6.081	0.676	4.2048	0.0000
BC	6	3.565	0.594	3.6981	0.0015
ABC	18	8.727	0.485	3.0171	0.0001
Error	288	46.278	0.161		
Total	335	738.136			

Factor A, type of wood; Factor B, type of varnish; Factor C, impregnation materials.

ing wood with Ba + Bx and varnishing develops the surface quality.

The R_a was the highest in Uludağ fir without impregnation and varnishing and the lowest in Scotch pine impregnated with Ba + Bx and then coated with Sv (Fig. 2).

CONCLUSION

The retention of impregnation material was different for different types of wood and impregnation materials. The highest retention was obtained by impregnation of Oriental beech, Oriental spruce, and Uludağ fir with Ba (13.15, 4.59, and 5.48 kg m^{-3}, respectively) and impregnation of Scotch pine with Ba + Bx (5.42 kg m^{-3}). The lowest R_a was obtained by impregnation of Oriental beech, Scotch pine, Oriental spruce, and Uludağ fir with Bx (9.32, 2.41, 2.03, and 2.73 kg m^{-3}, respectively).

Oriental spruce has a 20.2% smoother surface than Oriental beech, 8.4% smoother than Scotch pine, and 22% smoother than Uludağ fir. This may be because of the anatomic structure of the woods. It was reported that the anatomic structure, growth characteristic, and processes (steaming, seasoning, impregnation, machining, etc.) affect the surface roughness.[21] Roughness is also different in the tangential and radial directions in early and late wood.

The highest R_a value for the impregnation materials was measured in Bx (2.564 μm) and the lowest was in Ba + Bx (2.109 μm). Impregnation materials increase the surface smoothness, which was 32% for Ba, 22% for Bx, and 46% for Ba + Bx as compared with control samples. For the interaction of wood with impregnation material, the R_a was the highest in Bx (2.859 μm) and the lowest in Ba + Bx impregnated in Oriental spruce (1.798 μm). These values are less than the unimpregnated samples. The porosity in the wood materials may be the reason. Thus, the impregnation material decreases the surface roughness. The R_a was less in impregnated samples than in unimpregnated samples.[3]

TABLE VI
Results of Duncan Test

Process	*x*	HG	Process	*x*	HG[a]	Process	*x*	HG[a]
IV + Uv + C	5.692	A	II + Uv + Ba	3.533	EF	III + Wb + Ba	1.415	MNO
I + Uv + C	5.578	A	II + Uv + Ba + Bx	3.517	EF	III + Sv + C	1.363	NOP
IV + Uv + Bx	4.820	B	II + Wb + C	3.292	FG	II + Sv + C	1.304	NOPQ
I + Uv + Bx	4.338	C	I + Wb + Bx	2.964	GH	III + Wb + Ba + Bx	1.253	NOPQR
III + Uv + C	4.276	CD	IV + Wb + Bx	2.877	GHI	I + Sv + Bx	1.197	OPQRS
IV + Uv + Bx + Ba	4.196	CD	II + Wb + Ba	2.865	GHI	III + Sv + Bx	1.052	OPQRST
II + Uv + C	4.165	CD	III + Wb + C	2.810	HI	I + Sv + Ba	1.044	OPQRST
IV + Uv + Ba	3.936	CDE	IV + Wb + Ba	2.450	IJ	II + Sv + Bx	0.962	OPQRSTU
I + Uv + Ba	3.924	CDE	II + Wb + Bx	2.304	JK	IV + Sv + Bx	0.870	PQRSTU
I + Wb + C	3.915	CDE	IV + Wb + Ba + Bx	2.295	JK	IV + Sv + Ba + Bx	0.847	QRSTU
III + Uv + Ba	3.903	CDE	I + Wb + Ba + Bx	1.998	JKL	I + Sv + Ba + Bx	0.775	RSTU
II + Uv + Bx	3.862	CDE	II + Wb + Ba + Bx	1.973	KL	III + Sv + Ba	0.731	STU
I + Uv + Ba + Bx	3.828	DE	III + Wb + Bx	1.845	KLM	IV + Sv + Ba	0.640	TU
III + Uv + Bx	3.659	EF	I + Wb + Ba	1.835	KLM	III + Sv + Ba	0.602	TU
III + Uv + Bx + Ba	3.616	EF	I + Sv + C	1.707	LMN	III + Sv + Ba + Bx	0.525	U
IV + Wb + C	3.573	EF	IV + Sv + C	1.682	LMN	II + Sv + Ba + Bx	0.486	U

[a] Different letters in the columns refer to significant changes among interaction of wood, impregnation materials, and varnish at 0.05 confidence level ($LSD_{0.5} = 0.421$). I, Oriental beech; II, Scotch pine; III, Oriental spruce; IV, Uludağ fir; Uv, unvarnished; Wb, water-based; Sv, synthetic-based; Ba, boric acid; Bx, c, control, x, mean.

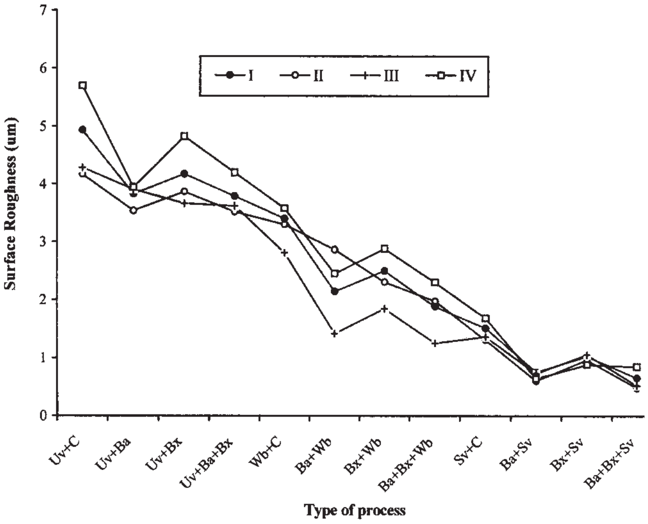

Figure 2 The surface roughness (R_a) values for different types of wood, impregnation materials, and varnishes.

The R_a for the type of varnish was the highest in Wb (2.479 μm) and the lowest in Sv (0.987 μm). Sv and Wb increased the surface smoothness by 77 and 41%, respectively, compared to control samples. For the combination of types of wood and varnishes, the R_a was the highest in Uludağ fir impregnated with Wb (2.799 μm) and the lowest in Scotch pine impregnated with Sv (0.838 μm). These values are less than unvarnished samples. Thus, varnishing develops the surface smoothness, depending on the type of varnishing material.

For the interaction of the impregnation material and varnish, the surface roughness was found to be the highest in Bx with Wb (2.498 μm) and the lowest in Ba + Bx with Sv (0.6588 μm). The surface roughness of varnished but unimpregnated samples was higher than the impregnated and varnished samples. According to this, boron compounds increase the surface smoothness in varnishes.

For the interaction of wood, impregnation material, and varnishing material, the R_a had the highest value in Uludağ fir varnished with Wb (5.692 μm) and the lowest in Scotch pine impregnated with Ba + Bx and coated with Sv (0.486 μm). According to these results, boron compounds developed the surface quality of our tested woods and varnishes.

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