The Effects of Steaming of Beech (*Fagus orientalis L.*) and Sapele (*Entandrophragma cylindricum*) Woods on the Adhesion Strength of Varnish

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ABSTRACT: In this study, it was investigated how steaming of beech (*Fagus orientalis L.*) and sapele (*Entandrophragma cylindricum*) woods effect the adhesion strength of some varnish types. With this objective, first of all, the surface roughnesses of the steamed and unsteamed specimens having tangential and radial surfaces and prepared from beech and sapele were measured (Kiliç et al., J Mat Proc Tech 2008, 199, 448). Subsequently, cellulosic, polyurethane and water-based bright varnishes were applied on these surfaces according to the principles stated in ASTM D 4541 and TS EN 24624 and the adhesion strength of the varnished layers were determined. According to the results of the study, the effects of the type of wood, steaming, surface and varnish types were found to be significant in the adhesion strength to the surfaces of the different varnish layers applied to the surfaces of different wooden materials. It was found that beech wood had a higher adhesion strength than sapele wood. The adhesion strength of steamed wooden materials had a lower strength compared with those that were unsteamed. The adhesion strength of specimens with a radial surface were found to be higher than the specimens with tangential surfaces. Whereas, in the varnish types, the highest adhesion strength was obtained with the polyurethane varnish, which completed the chemical reaction on the surfaces of the wooden material. In conclusion, it could be proposed to use beech wood materials having a radial surface in the jobs requiring a high adhesion strength, to sand once again the material due to the increase in roughness of steaming and to use polyurethane varnish. © 2009 Wiley Periodicals, Inc. J Appl Polym Sci 113: 3492–3497, 2009

Key words: coatings; beech; sapele; steaming; adhesion strength; varnishes

INTRODUCTION

The fact that wooden material has a large number of unique advantages makes its use attractive in many areas of application. Wooden material, with its structure as well as the effect of its natural appearance, is preferred in the production of furniture and decoration elements. The color and texture as much as the mechanical characteristics are also of importance in the selection of wood types. However, wooden materials, due to their organic formation, do not show resistance for a long period of time against external factors to which they are subjected in their places of use. Consequently, it is imperative to protect with various substances the furniture and decoration elements produced with wooden materials.[1] Varnishes are in the lead of these substances. To cover with different layers of varnish with the objective of protecting the surfaces of wooden materials against external factors is the most extensively used method.[2]

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Steaming is one of the most important processes in the manufacturing of specialized wood products, such as flooring, bent wood members and various types of furniture units.[3] The main objective of steaming is to make the wood softer, more plastic and to blend the color difference between heartwood and softwood, so that it would result in a more uniform appearance. The steaming of wood at atmospheric or a low gage pressure plays an important role on the color uniformity, improved dimensional stability, and higher resistance against biological deterioration during its service life for flooring production.[4] Steaming may also influence the surface roughness characteristics of wood, which may lead to an extra sanding process to attain an acceptable surface quality for flooring material.

Wood treated at high temperature has less hygroscopicity than natural wood. Heating wood permanently changes several of its chemical and physical properties. The change in properties is mainly caused by thermic degradation of hemicelluloses. Theoretically, the available OH groups in hemicellulose have the most significant effect on the physical properties of wood. Heat treatment lowers water uptake and the wood cell wall absorbs less water because of the decrease in the number of hydroxyl groups in the wood. The swelling and shrinking are lower due to the reduced number of hydroxyl groups. In addition to better durability, the advantages of heat treated wood are reduced hygroscopicity and improved dimensional stability. It stabilizes around a humidity of 4-5% rather than 10-12%.[5,6]

Many studies have been made up until the present-day for determining the characteristics of varnishes. It was stated that the type of wooden material is not influential on the adhesion strength and that the real influence is in the paint types and that the best result is obtained with synthetic paint.[7] The hardness of the layer thickness, brightness and the adhesion strengths to the surface were examined in the wood material varnishes. According to the results of the studies, the highest value in the measurements of adhesion strength to the surface were obtained in oak and acrylic varnish.[8] The hardness of the varnish layers, the brightness and adhesion strength to the surface used on the furniture surfaces made from wood were examined from the aspect of their resistances to dry and damp heat, burning cigarettes, acetone, detergent, acetic acid, and sodium hydroxide. In conclusion, the differences in the wood types were not influential on the hardness of the varnish layers. The real influence was in the type of varnish and it was measured that the highest hardness was in the polyester varnishes.[9] It was determined that the type of wood and the amount of humidity were not influential on the adhesion strength values to the surface of the varnishes and that the real influence was stemming from the type of varnish applied.[10] It was stated that the adhesion to wood of the polyurethane varnishes was higher than the other varnishes and that the lowest value was found in the synthetic varnishes.[9] It was determined that the hardness, brightness and adhesion strength to the surface of different types of water-based varnishes applied on the wood types with different methods were lower than the solvent-based varnishes.[11] The adhesion strength to the surface of solvent-based varnishes applied to the surfaces of different wooden materials having different humidities were studied. It was stated that on the basis of the amount of humidity, the highest adhesion strength was found to be 8%.[12] The effect of color lightening chemical substances in the upper surface processes in wooden materials were studied. It was determined that the water-soluble varnishes were successful in the adhesion strength to the surface.[13] Mehmet Budakçi designed and realized the production of an adhesion test equipment, which operates with a pneumatic system, to measure the adhesion strength of the protective layers. He made an exemplary study and determined the adhesion strength to the surface of the varnish layers by applying cellulosic, polyurethane, acrylic and water-soluble varnishes on Scotch pine (*Pinus sylvestris* L.), fir (*Abies* sp.), beech (*Fagus orientalis* L.), and sessile oak (*Quercus Petreae* L.) woods. It was determined that the influence of wood type and varnish type was significant on the adhesion strength to the surfaces of different varnish layers applied to the surfaces of different wooden materials. It was also determined that the influence of the test equipment and differences in the layer thicknesses were insignificant. Furthermore, it was determined that the adhesion strength of the varnishes on broad-leaved woods was high and that it was low in the coniferous woods. The highest adhesion strength was obtained in the polyurethane and acrylic varnishes, which completed the polymerization on the surface of the materials.[14] It is stated that impregnated substances decrease 3-5% and that chemicals used in lightening the color decrease 1-3% the adhesion strength to the surface of the varnishes.[15–17] Furthermore, the effects of impregnated substances on the brightness, color, hardness and burning of the varnish types have been investigated in many recent studies.[18–22]

Sapele (*Entandrophragma cylindricum*) is a native species of Africa with a distribution ranging from the Ivory Coast to Cameroon and through Zaire to Uganda. Its heartwood is medium to fairly dark reddish brown or purple brown and its sapwood is pale yellow. The wood has a specific gravity of 0.55 with easy machinability and finishing properties.[23–25] Beech (*F. orientalis L.*) is a native species of Eastern Europe and Western Asia. The wood is whitish to pale brown having a specific gravity of 0.72 with an excellent bending property under steamed conditions. Beech units are ideal for manufacturing various types of furniture parts. Broad rays of beech are visible on its tangential surface. Both beech and sapele, which are widely used for flooring material, are steamed to produce a deeper color, which is in great demand among the flooring material consumers.[3]

It was investigated in this study how steaming the wooden materials effected their adhesion strength to the varnishes. Water-based, cellulosic and polyurethane varnishes were applied on the tangential and radial surfaces of the specimens prepared from beech and sapele with this objective. Subsequently, the adhesion strengths to the surfaces of the varnished layers were determined.

MATERIAL AND METHODS

Material

Wood materials

As mentioned above, beech and sapele were the woods used as test specimens. Beech was obtained

TABLE I
Properties of Varnishes[18,27]

Type of varnish	pH	Density (g cm^{-3})	Viscosity (snDINCup/4 mm)	Amount applied (g m^{-2})	Nozzle gap (mm)	Air pressure (bar)
Polyurethane (filler)	5.94	0.98	18	160	1.8	2
Polyurethane (finishing)	4.01	0.99	18	160	1.8	2
Water based (primer) ASTM D 17	9.17	1.014	18	150	1.3	1
Water based (filler) ASTM D 65	9.30	1.015	18	80	1.3	1
Water based (finishing) ASTM D 45	8.71	1.031	18	80	1.3	1
Cellulosic (filler)	2.9	0.955	20	125	1.8	3
Cellulosic (finishing)	3.4	0.99	20	125	1.8	3

from Bolu and sapele was randomly obtained from lumber merchants in Ankara. Special emphasis was placed on the selection of the wood material (lumber). Accordingly, wood with no defects, suitable, knotless, normally grown wood materials (without zone lines, wood without reaction and without decay, insects, or fungal infections) were selected according to the TS 2470 standard.[26]

Varnishes

The cellulosic, water-based and polyurethane varnishes were obtained from the companies in Ankara. The recommendations of the producers were conformed to in the application of the varnishes. The technical characteristics of the varnishes are given in Table I.[18,27]

Methods

Preparation of the test specimens

Initially, the steaming process of the specimens prepared was made for the test and the surface roughnesses were measured. These results were made known with a previous study.[3] Accordingly, a total of 12 specimens, 6 for beech and 6 for sapele, were used for the experiments. Specimens with a length of 1 m, a width of 10 cm and a thickness of 1 cm with tangential (flat sawn) or radial grain (quarter sawn) orientations were cut from two species of large lumber. The specimens were planed and sanded with 60-grit and 80-grit sandpaper. First, the specimens were air-dried to a moisture content of 30–35% before their moisture content was reduced to 10% in a laboratory-type kiln. Later, they were steamed for 10 minutes in a tank at a temperature of 108°C and under a pressure of 0.22 bars. Finally, the specimens were conditioned in a climate-controlled room with a relative humidity of 65% at 20°C until they reached an equilibrium moisture content.[3]

A fine stylus-type Mitutoya Surftest SJ-30 equipment consisting of the main unit and the pick-up was used to evaluate the surface characteristics of the specimens. The pick-up has a skid type diamond stylus with a 90° tip angle and with a 5 μm tip radius. The stylus traverses the surface at a constant speed of 1 mm/s over a 12 mm tracing length by converting the vertical displacement of the stylus into an electrical signal. A representation of surface can be obtained in the form of a graph. Thirty random roughness measurements from the surface of each specimen were taken before and after they were steamed.[3]

The test specimens measured for surface roughnesses were cut to the dimensions of 10 x 10 x 1 cm and were kept in a climatization chamber at a temperature of 20 ± 2°C and a relative humidity of 65 ± 5% until they reached an unchanging weight for once again reaching a 12% humidity.

Varnishing

The test specimens were varnished according to ASTM D 3023.[28] The recommendations of the producer were taken into consideration for the composition of the ratio of the solvent and hardener and one or two finishing layers were applied after the filling layer. The spray nozzle distance and pressure were adjusted according to the recommendations of the producer and moved in parallel with the surface of the specimen at a distance of 20 cm. Varnishing was made at a temperature of 20 ± 2°C and a relative humidity of 65 ± 5%. Dry film thicknesses were determined before the tests according to the ASTM D 1005 standard.[29] The thickness of the varnish layers was measured with a Mitutoya comparator, which has a sensitivity of 5 μm. The layer thickness was found to be 98 μm in the cellulosic varnish, 103 μm in the polyurethane varnish, and 88 μm in the water-based varnish.

Adhesive

In the tests, the "404 Steel Adhesive," which has a high bonding strength and which does not have a

TABLE II
Average Roughness Values of the Specimens from Two Species[3]

Roughness parameters (μm)	Beech (*Fagus orientalis* L.)				Sapele (*Entandrophragma cylindricum*)			
	Tangential		Radial		Tangential		Radial	
	Before steaming	After steaming	Before steaming	After steaming	Before steaming	After steaming	Before steaming	After steaming
R_a	6.67 (1.18)	11.08 (1.14)	6.68 (1.12)	12.10 (0.59)	9.26 (0.31)	11.05 (0.74)	8.95 (0.78)	12.71 (0.36)
R_z	62.54 (11.99)	88.38 (11.73)	61.40 (7.53)	101.46 (7.28)	107.95 (6.44)	120.93 (8.34)	97.34 (8.10)	123.25 (8.99)
R_k	20.51 (2.05)	37.22 (3.63)	21.89 (3.34)	42.42 (1.95)	20.41 (1.76)	28.89 (1.59)	18.30 (1.78)	35.22 (0.69)
R_{pk}	7.76 (1.34)	16.16 (2.86)	7.61 (1.88)	19.15 (1.79)	8.71 (1.34)	12.18 (2.34)	6.70 (0.47)	12.04 (0.89)
R_{vk}	14.94 (2.89)	17.28 (6.52)	12.51 (7.63)	17.15 (3.72)	39.77 (1.31)	39.42 (1.65)	39.45 (0.68)	40.34 (0.87)

Values in prantheses are SD = standard deviation.

solvent effect on the double-compound epoxy-resin varnish layers, was used with the calculation of 150 ± 10 g/m^2 according to the ASTM D-4541[30] and TS EN-24624.[31] The tensile cylinders having a diameter of 20 mm were bonded to the specimen surfaces at normal room temperatures with the aid of a mold. The surfaces were covered with a protective layer, which provided for complete dryness. Two hours later, the excess adhesive, which started to become gelled, was cleaned off with a help of a spatula and it was left to dry for a period of 24 h. The layers on the surfaces, on which the test cylinder was bonded, were cut with the help of a cutter up to the surface of the material.

Bonding to the surface test

In the study, the bonding strengths to the surface of the varnished layers were determined in the adhesion test equipment, which operates with a pneumatic system that was made by Mehmet Budakçi, in conformance with the principles of the ASTM D-4541 and the TS EN 24624.

In the measurements, the resistance to bonding (X);

$$X = 4F/\pi.d^2 \text{Mpa} \quad (1)$$

was calculated from the equation[30,31]

F = Strength at the moment of breaking (Newton)

d = Diameter of the tensile cylinder (mm)

Data analyses

Two different types of wood (beech and sapele), two types of directions (tangential and radial), two types of processes (steamed and unsteamed) and three types of varnish (cellulosic, polyurethane, and water-based varnishes), and five specimens for each parameter were used to prepare a total of 120 samples (2 x 2 x 2 x 3 x 5). The F test was made on the specimens with the SPPS 11.5 package program. In case the differences among the groups were statistically significant, then a comparison was made with the Duncan test at a level of confidence of (α = 0.05).

RESULTS AND DISCUSSION

The roughness values of sapele and beech, which were made known with a previous study, are given in Table II.[3] It is observed that the surface roughness values increase with the influence of steaming.

Accordingly, as the surface roughness increases, the adhesion strength decreases. The average adhesion strength of varnish in the wooden specimens in which the steaming process was made is 2.35 Mpa and the average adhesion strength of varnish in the wooden specimens in which the steaming process was not made is 2.61 Mpa. The number of the OH groups decreases during the heating process.[5,6] Due to this decrease, it could be that the adhesion strength of the varnish of the steamed wooden material could be lower.

Average roughness values of the specimens from two species[3]

The descriptive statistical values for the type of wood, steaming process, direction and type of varnish are given in Table III. Of the wooden types, the average adhesion strength of varnish in beech was found to be 2.60 Mpa and the average adhesion strength of varnish in sapele was found to be 2.36 Mpa. The differences between the wooden types stem from the anatomic structure of the wood. Since the adhesion strength of the sapele wood is lower compared with the beech and the extractive ratio of sapele is higher compared to beech, it can be explained due to the fact that the diameters of the vessels of sapele are larger than the diameters of the vessels of beech.

TABLE III
Descriptive Statistical Values for the Type of Wood, Steaming Process, Direction and Type of Varnish (Mpa)

	Wood types		Steaming		Directions		Varnish types		
	F = 6.845 *P* = 0.010		F = 8.384 P = 0.005		F = 27.036 *P* = 0.000		F = 11.635 *P* = 0.000		
Statical values	Beech	Sapele	Steamed	Unsteamed	Tangential	Radial	Pu	Cl	Wb
x	2.60	2.36	2.35	2.61	2.26	2.70	2.77	2.37	2.30
Min.	1.59	1.40	1.40	1.90	1.56	1.40	1.59	1.66	1.40
Max.	3.38	3.26	3.27	3.38	3.20	3.38	3.27	3.15	3.38
S.D.	0.48	0.52	0.55	0.44	0.46	0.47	0.50	0.36	0.53

x, mean; Min, minumum; max, maximum; SD, standard deviation; Pu, Polyurethane; Cl, Cellulosic; Wb, Water based.

Descriptive statistical values for the type of wood, steaming process, direction and type of varnish

The influence of the type of wood, steaming process, direction and type of varnish were found to be significant at a reliability of 95%. The Duncan test was applied to determine among which groups there was a difference in the varnish type and the test results are given in Table IV. It was found that the adhesion strength to varnish, according to the wood types, was higher in beech. The wooden materials that are not subjected to the steaming process had a higher adhesion strength. In the same manner, the highest adhesion strength values were in the radial surface and of the varnish types, in the polyurethane varnish.

The duncan test results for the varnish types (Mpa)

The results of the multiple variance of analysis for wood types, steaming, direction and varnish types for adhesion strength are given in Table V. According to this table, the interactions of the wood type-varnish, the wood type-direction-varnish, and the steam-wood type-direction-varnish are significant.

Multiple variance of analysis for wood types, steaming, direction and varnish types for adhesion strength

Conclusion

The average adhesion strength of varnish on the tangential surfaces is 2.26 Mpa and it is 2.36 Mpa on the radial surfaces. The spring and summer wood layers on the radial surfaces are found in the form of narrow strips and the spring and summer wood layers of the annual rings on the tangential surfaces cover an extensive area. This situation affects the holding strength of these surfaces to the surface materials. The surface material on the summer wood sheds quickly by being affected more from rain and sun. Consequently, it is stated that the surface process substance of the radial surfaces is held better.[32] The results obtained are in conformance with this situation.

Among the varnish types, the polyurethane varnish had the highest adhesion strength at 2.77 Mpa. It was followed by cellulosic varnish at 2.37 Mpa and water-based varnish at 2.30 Mpa, respectively. According to the results of the Duncan test, there is no difference in the level of significance at $\alpha = 0.05$ between the adhesion strengths of the cellulosic and water-based varnishes. In a similar study, it was determined that the adhesion strengths of the water-based varnishes were lower than that of solvent-based varnishes.[11] The fact that polyurethane varnish had the highest adhesion strength is also in

TABLE IV
The Duncan Test Results for the Varnish Types (Mpa)

Varnish Types	x	HG
Polyurethane	2.77	A
Water-based	2.30	B
Cellulosic	2.37	B

x: mean, HG: degrees of homogeny.

TABLE V
Multiple Variance of Analysis for Wood Types, Steaming, Direction and Varnish Types for Adhesion Strength

Source	Sum of squares	Degrees of freedom	Mean square	F value	*P* < 0.05
Factor A	2.094	1	2.094	17.827	0.000
Factor B	1.730	1	1.730	14.735	0.000
Factor C	5.883	1	5.883	50.095	0.000
Factor D	5.235	2	2.618	22.290	0.000
A*B	0.248	1	0.248	2.108	0.150
A*C	0.289	1	0.289	2.462	0.120
B*C	0.039	1	0.039	0.334	0.565
A*B*C	0.008	1	0.008	0.067	0.797
A*D	0.448	2	0.224	1.908	0.154
B*D	0.959	2	0.480	4.084	0.020
A*B*D	0.012	2	0.006	0.050	0.952
C*D	0.329	2	0.164	1.401	0.251
A*C*D	0.401	2	0.201	1.708	0.187
A*C*D	1.477	2	0.739	6.289	0.003
A*B*C*D	1.133	2	0.567	4.825	0.010
Total	772.139	120			

Factor A: Steaming, Factor B: Wood types, Factor C: Direction, Factor D: Varnish types.

conformity with the studies made previously.[9,14,32] The adhesion of the wood by the polyurethane varnishes, which complete polymerization on the surface of the wooden material, are higher compared with other varnishes. Consequently, it is known that the adhesion strength is high.[14]

In conclusion, it could be recommended that beech materials having a radial surface and varnished with polyurethane should be used in places of use, which require a high adhesion strength. However, due to the fact that the steaming process increases the roughness of the wooden materials, it would be more appropriate to use steamed wooden materials by sanding once again after the surface process in accordance with the objective of use. Furthermore, it would also be useful to conduct studies related to this subject by taking into consideration many factors, such as steaming time, different wood species, etc.

References

1. Söğütlü, C.; Sönmez, A. J Fac Eng Arch Gazi Univ 2006, 151.
2. Highley, T. L.; Kicle, T. K. Phytopsthology (Blanchette, RA, et al.,) 1990.
3. Kiliç, M.; Hiziroglu, S.; Güllü, C.; Sezgin, Z. J Mat Proc Tech 2008, 199, 448.
4. McKenzie, W. M. For Prod J 1960, 10, 447.
5. Inoue, M.; Norimoto, M.; Tanahashi, M.; Rowell, R. M. Wood Fiber Sci 1993, 25, 224.
6. Korkut, D. S.; Korkut, S.; Bekar, I.; Budakçi, M.; Dilik, T.; Çakicier, N. Int J Mol Sci 2008, 9, 1772.
7. Kaygin, B.; Akgün, E. Int J Mol Sci 2008, 9, 476.
8. Budakçi, M. J Polytec 1998, 10, 1.
9. Sönmez, A. Durability of Varnishes Used on Surfaces of Wooden Furniture in Response to Important Physical, Mechanical and Chemical Effects, Ph.D. Thesis, Gazi University Institute of Science, Ankara, 1989.
10. Pelit, H. The Effect of the Moisture Content of Wood on Layer Properties of Water Borne Varnishes, Master's Thesis, Gazi University, Institute of Science, Ankara, 2007.
11. Sönmez, A.; Budakçi, M.; Yakin, M. J Polytec 2004, 7, 3.
12. Bayram, M. The Effects of the Moisture Content of Wood on Adhesion Strength of Varnishes, Master's Thesis, Gazi University, Institute of Science, Ankara, 2004.
13. Atar, M.; Keskin, H.; Yavuzcan, H. G. J Coat Tech 2004, 1, 498.
14. Budakçi, M. J Polytec 2006, 9, 53.
15. Özçiftçi, A.; Özpak, A. S. Con Build Mat 2008, 22, 513.
16. Sönmez, A.; Budakçi, M. GU J Sci 2001, 14, 305.
17. Özçifçi, A.; Atar, M.; Uysal, Burhanettin. Turk J Agric For 1999, 23, 763.
18. Keskin, H.; Atar, M. J App Polym Sci 2008, 108, 3361.
19. Atar, M. J App Polym Sci 2008, 107, 3981.
20. Keskin, H.; Atar, M. J App Polym Sci 2007, 106, 3952.
21. Keskin, H.; Atar, M. J App Polym Sci 2007, 106, 4018.
22. Atar, M.; Keskin, H.; Çolakoğlu, M. H. J App Polym Sci 2007, 103, 1048.
23. Cundroff, M. Tropical Timber of the World, USDA Forest Service: Washington, D.C., 1984; p 820.
24. Flynn, H.; Holder, C. Useful Woods of the World; Forest Prod Soc.: Madison, 2001; p 618.
25. Hoadley, B. Identifying Wood; The Taunton Press Inc.: Newton, CT, 1990.
26. TS 2470.; Wood-Sampling Methods and General Requirements for Physical and Mechanical Tests, Ankara, Turkey, 1976.
27. DYO, Dewilux, Technical Bulletin, Dewilux Factory, Izmir, Turkey, 1996.
28. ASTM D 3023.; Standard Practice for Determination of Resistance of Factory Applied Coatings on Wood Products of Stain and Reagents. American Society for Testing and Materials, 1998.
29. ASTM D 1005.; Standard Test Method for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers. American Society for Testing and Materials, 2001.
30. ASTM.D 4541.; Standard Test Method for Pull-off Strength of Coatings Using Portable Adhesion Testers. American Society for Testing and Materials, 1995.
31. TS EN 24624.; Paints and Varnishes-Pull-of Test. Turkish Institute of Standards, Ankara, 1996.
32. Kurtoğlu, A. Surface Finishings General Information, Istanbul University, Forestry Faculty, Department of Forestry Industrial Engineering: Istanbul, 2000; 1: p 1.