The Influence of the Impregnating Chemicals on the Bonding Strength of Impregnated Wood Materials

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Received 9 May 2007; accepted 6 September 2007
DOI 10.1002/app.27370
Published online 19 November 2007 in Wiley InterScience (www.interscience.wiley.com).

ABSTRACT: In this study, it is aimed to determine the bonding strength of white oak (*Quercus petreae L.*) and chestnut (*Castanea sativa Mill.*) woods impregnated with borax and zinc chloride. Within this purpose, the experimental samples were bonded with Polyvinyl-acetate and polyurethane based Desmodur-VTKA (D-VTKA) adhesives according to BS EN 205 standards after they had been prevacuumed with a pressure equal to 760 $mmHg^{-1}$ with impregnating at 2 atm pressures for 60 min according to ASTM-D 1413 standards and applied vacuum-impregne-vacuum method. During the experiments, the retention amount, the retention proportion, and the bonding strength values of the samples were determined. According to the test results, the highest values of retention amount, and bonding strength were obtained from the wood material impregnated with zinc chloride. The impregnating materials had a negative effect on bonding strength. © 2007 Wiley Periodicals, Inc. J Appl Polym Sci 107: 2871–2876, 2008

Key words: woods; impregnating; adhesives; zinc chloride; borax

INTRODUCTION

Wood materials have high strength quality compared with their lightness, they have high performance in sound absorbing and thermal resistance, it is easy to operate, easy to nail down and join, they have high strength against chemicals and the most important property of wood materials is that they can be recycled. Although they have this kind of master properties, they can easily be burnt, and can be damaged by harmful insects.[1] The surface of wood material can be coated or impregnated to block or to decrease this kind of disadvantages.

At the end of impregnating process, the lifetime of wood material gets about seven to eight times longer. The wood materials, which are unimpregnated and left under natural conditions can be damaged down within 5 years.[2]

If laminating is applied after the veneers have been impregnated as an alternative to wood material, it is certain that it provides much more advantages in using them.[3]

Laminated wood materials are named differently according to the layer thicknesses used. A material having a thickness of 25.4–50.8 mm used in producing large dimensioned laminated wood material is used in building sector and it is named as adhesived laminated lumber (GLULAM). In addition, a veneer type having a thickness of 3.2 mm is used in pruducing furniture and those kind of laminated materials are named as laminated veneer lumber or MICROLAM.[4]

Not to damage the structure of laminated wood material, the placement of annual rings must be paid attention, while preparing the layers. The reason is that, the wood material grows up differently in tangential and radial directions. As known, the dimensional stability changes according to wood types as follows, 3.5–15% in tangential direction, 2.4–11% in radial direction and 0.1–0.9% for parallel to grain direction.[5]

The strength of LVL is related with the quality and technical property of the adhesive used in bonding, and the wood structure used in laminating process, surface roughness, pressing pressure and pressing time. If the different wood types are pressed at the same time, the pressing time is determined acording to the hardness of the wood material. The pressing pressure must be between 0.6 and 1 N/mm^2 for soft wood, and between 0.2 and 1.6 N/mm^2 for hard wood.[6]

It was reported that laminated wood materials, which are high-grade in aeshtetical economical and technological properties compared with massive wood materials, should be preferred in producing furniture, especially for resistive framework materials of wardrobe, table, chair, shelf etc.[7]

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Journal of Applied Polymer Science, Vol. 107, 2871–2876 (2008)

In this study, it was aimed to determine the density and bonding strength of impregnated white oak and chestnut woods. The veneers were impregnated with borax (Bx) and zinc chloride ($ZnCl_2$) chemicals according to ASTM D 1413-76 standards and bonded with Polyvinyl-acetate (PVAc) and D-VTKA adhesives.

MATERIALS AND METHOD

Woods

The following wood materials were used. White oak (*Quercus petreae L.*) with a density of 0.54 g/cm^3, and chestnut (*Cestanea sative Mill.*) with a density of 0.48 g/cm^3, were purchased from a local supplier. Pieces were cut from the timbers with the dimensions 125 $\times$ 20 $\times$1 0 mm.

Adhesives

PVAc adhesive was preferred in the production of LVL. The application of this adhesive is very easy and it does not damage tools during the cutting process. However, the mechanical strength of PVAc adhesive decreases when the temperature increases. It loses bonding strength when the temperature is above 70°C. Using 180–200 g/m^2, the adhesive seems to be suitable if it is applied to only one surface. The density of PVAc adhesive should be 1.1 g/cm^3, the viscosity 16,000 $\pm$ 3,000 mPa s, and the pH value and ash ratio should be 5 and 3%, respectively. PVAc adhesive was supplied from Bitlis Group, a producer firm in Izmit, Turkey.[8]

Desmodur-VTKA is a single component polyurethane based adhesive, which is widely used in assembly process in the furniture industry.[8] It is used for gluing wood, metal, polyester, stone, glass, ceramic, PVC and other plastic materials. Its application is specially recommended in locations subjected to high-level humidity. Gluing process was carried out at 20°C and 65% relative humidity. According to the producer firm's advice, adhesive was applied 180–200 g/m^2 to the surfaces. Its viscosity was 14,000 $\pm$ 3000 mPa s at 25°C, density 1.11 $\pm$ 0.02 g/cc at 20°C and it has strength below freezing temperature.

Impregnating chemicals

The following impregnating solutions supplied by the Hemel Company (Turkey) were used. Bx and $ZnCl_2$ were preferred in this research, widely found in Turkey and effective against biotic and abiotic damages. As impregnating chemicals, (Bx) ($Na_2B_4O_7 \cdot 5H_2O$) containing 21.28% Na_2O, 47.80% B_2O_3, 30.92% H_2O, and $ZnCl_2$ were used for fire-retardant.

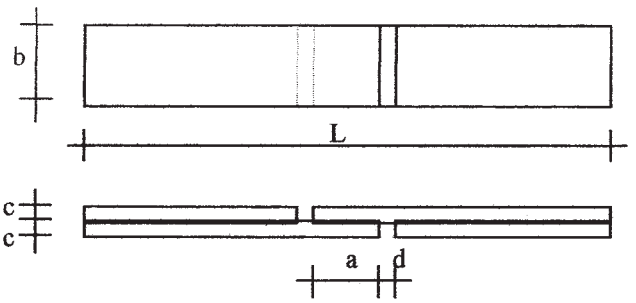

Figure 1 The test sample (size given in mm).

Preparation of test samples

While preparing laminated wood materials, oak and chestnut woods were used. Papel layers having a thickness of 5 mm were obtained by using ''sliced method'' from the timbers that did not have growing detect. The veneers were impregnated with Bx and $ZnCl_2$. Before and after impregnating process, the weight of all test samples was measured with an analytic balance of $\pm$0.01 g sensitivity.

For impregnating process, the samples were pre-vacuumed under a pressure equal to 760 mmHg^{-1} for 60 s according to ASTM-D 1413–76 standards.[9] At second stage, they were left in a solution under 2 atm pressures for period of 60 min. At the third stage, the samples were vacuumed under a pressure equal to 760 mmHg^{-1} for 60 min and residual impregnating left on and in the material, were taken back. The weights of samples were measured at each stage. After the impregnating processes, the test samples were kept in an air-circulating place for 15–20 days for the solvent to vaporize, and they were left in drying oven at 103 $\pm$ 2°C until their weights become stable. Their weights have been determined by measuring after they were got cold in a desiccator including calcium cloride.

While preparing impregnating materials, pure water was used and the mixtures were prepared acoording to weight standard as %. Dry Bx of 10% ($Na_2B_4O_7 \cdot 5H_2O$) and $ZnCl_2$ were mixed under room temperature by solving them in pure water. Densities and pH of the solutions were determined before and after impregnating. For the impregnating

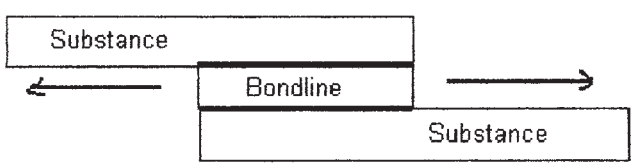

Figure 2 Test apparatus of the bonding strength.

TABLE I
Properties of Impregnating Chemicals

Impregnating chemicals	Viscosity (20°C) 4 mm/ Din Cup/sn	Solvent	Solution concentration (%)	Temperature (°C)	pH		Density (g/mL)	
					B.I	A.I	B.I	A.I
Borax	8	Distilled water	10	20	9.0	9.2	1.06	1.06
Zinc Chloride	8	Distilled water	10	20	6.0	6.3	1.07	1.07

B.I., before impregnating; A.I., after impregnating.

process, the dipping process was applied for 36 h according to ASTM-D 1413 standards. Before and after impregnating, the test samples were oven dried,[10] the amount of retention (R, kg/m^3) and ratio of retention (R, %) were calculated as follows:

$$R = \frac{GC}{V} \times 10^3 \,(\mathrm{kg/m^3}) \tag{1}$$

$$R\,(\%) = \frac{M_{di} - M_d}{M_d} \times 100 \tag{2}$$

where $G = T_2 - T_1$, T_2 is the sample weight after impregnating (kg), T_1 is the sample weight before impregnating (kg), M_{di} is the full dried weight after impregnating (kg), M_d is the full dried weight before impregnating (kg), V is the volume of the sample (m^3), C is the concentration of solution (%).

For determining the air-dry densities of wood materials used for the preparation of test samples were determined according to TS (Turkish Standards) 2471 and 2472.[11,12] The test samples with dimensions of 20 × 30 × 30 mm^3 were kept under the conditions of 20°C ± 2°C and 65% ± 5% relative humidity until their weight become stable. The weights were measured with an analytic balance of ±0.01 g sensitivity. Afterwards, the dimensions were measured with a digital compass of 0.01 mm. The air-dried densities (δ_{12}) of the samples were calculated with the following formula:

$$\delta_{12} = M_{12}/V_{12}\,(\mathrm{g/cm^3}) \tag{3}$$

The veneers cut from sapwood were kept in a conditioning room having conditions of 20°C ± 2°C temperature and 65% ± 3 relative humidity until they reached to 12% humidity. The oven dried veneers classified according to each impregnating type and advesive type. Afterwards, aproximately 180–200 g/m^2 adhesive was applied to the bonding surface of samples. Bondline was obtained with 0.5 N/mm^2 press pressure and 12 h pressing time. The test samples are given in Figure 1, where *a* is the width of bonded surface (10 mm) and *b* is the length of bonded face (20 mm) and the others are *c*: 5 mm, *d*: 3 mm, *L*: 150 mm.

Application of experiment

The test of shear strength was carried out according to the principles of BS EN 204[13] and TS EN 205[14] standards. As seen in Figure 2, the loading speed

TABLE II
Amounts and Ratios of Retention According to Layer Thickness and Impregnating Materials

Wood	Impregnating material	Number of weight	Average weights during tests (gr)	Standard deviation	Retention amount (kg/m^3)	Retention ratio (%)
Chestnut	Zinc chloride	I	64.76	1.20	12.86	17.20
		II	75.90	1.09		
		III	124.78	3.09		
	Borax	I	64.76	1.25	10.5	14.11
		II	73.90	1.23		
		III	117.80	3.23		
White oak	Zinc chloride	I	181.12	1.56	10.48	5.03
		II	190.23	1.67		
		III	220.34	3.89		
	Borax	I	181.12	1.89	7.41	3.50
		II	187.56	1.96		
		III	211.89	3.89		

I: Full dry weight before impregnating (g); II: Full dry weight after impregnating (g); III: Full damp weight after impregnating (g).

TABLE III
Effect of Impregnating Material, Glue Type, and Wood Material Type on Bonding Strength

Woods	Types of adhesive	Impregnating	Average values (N/mm^2)	Standard deviation	Decreases (%)
White oak	PVAc	Control	14.2	0.55	–
		Zinc chloride	10.7	0.30	24.26
		Borax	10.6	0.33	24.82
	D-VTKA	Control	10.0	0.30	–
		Zinc chloride	6.2	3.16	37.61
		Borax	6.4	0.21	35.52
Chestnut	PVAc	Control	15.4	0.33	–
		Zinc chloride	14.0	0.65	9.50
		Borax	13.0	0.66	15.96
	D-VTKA	Control	9.9	0.42	–
		Zinc chloride	8.5	0.20	13.33
		Borax	8.6	0.19	12.92

was 50 mm/min. The loading was continued until a break or seperation occurred on the surface of the test samples, meanwhile, observing load (F_{max}), bonding surface of sample (A, in mm^2) and shear strength (σ_y) were calculated as follows:

$$\sigma_y = \frac{F_{max}}{A} = \frac{F_{max}}{ab} \ (N/mm^2) \quad (4)$$

where a is the width of bonded surface (10 mm) and b is the length of bonded face (20 mm).

By using two different types of adhesive, three impregnating chemicals, two different species of wood as parameters, a total of 120 samples ($2 \times 3 \times 2 \times 10$) were prepared with 10 samples for each parameter. Multi variance analysis was used to determine the difference between the bonding strength of the joining surfaces of the prepared samples. It was determined by the Duncan test that there is asignificant difference between the groups.

RESULTS AND DISCUSSION

The features of impregnating materials are given in Table I.

The pH values and densities of solutions measured before and after impregnating process did not change much that would influence the result. That was because of the fact that each impregnating material was processed with a new and fresh solution. The higher density of white oak compared with chesnut together with PVAc adhesive can provide higher adhesion on wood surface.

Retention quantities

The average retention amounts and ratios of impregnating materials are given in Table II.

The highest retention amount and ratio were obtained in chesnut impregnated with $ZnCl_2$ as 12.86 kg/m^3, as 17.20%, and the lowest was in white oak impregnated with Bx as 7.41%, 3.50, respectively. The retention amounts were enhanced in both species due to the length of impregnating period (12 h). This can be because of the impact of permeability. As well as that, extractive materials or compounds and thyll in chesnut could affect this result. Amount of retention and retention ratio of $ZnCl_2$ solution have the highest value, this can be due to its high density value. Obtaining high retention value according to wood species can be because of the low density of chestnut compared with oak. Sapwood of chestnut has norrow cross-section and tracheid diameters, and it has wider lumen although annual-rings have large trache.[5] Thus, this might have increased the retention ratio of impregnating material.

Bonding strength

The average bonding strength values obtained for different factors are given in Table III. The results of

TABLE IV
Multiple Variance Analysis of Bonding Strength Relating to Wood Material Type, Glue Type, and Impregnating Material

Source of variance	Sum of square	Degrees of freedom	Mean square	F-value	$P \leq 0.05$
A	103.695	1	103.695	656.081	0.000
B	663.687	1	663.687	4199.168	0.000
C	184.280	2	92.140	582.972	0.000
A × B	5.047	1	5.047	31.933	0.000
A × C	27.560	2	13.780	87.185	0.000
B × C	3.052	2	1.526	9.656	0.000
A × B × C	1.628	2	0.814	5.151	0.007
Error	17.070	108	0.158		
Total	1006.019	119			

Factor A: types of wood (white oak, chestnut); Factor B: adhesives (PVAc, D-VTKA); Factor C: impregnating materials (borax, zinc chloride).

TABLE V
Duncan Test Results of Bonding Strength (N/mm^2)

Wood material type, glue type, and impregnating materials	Average value (N/mm^2)	H.G.	Decrease (%)
Chestnut – PVAc – control	15.4	A	–
White oak – PVAc – control	14.2	B	–
Chestnut – PVAc – zinc chloride	14.0	B	9.5
Chestnut – PVAc – borax	13.0	C	15.9
White oak – PVAc – zinc chloride	10.7	D	24.2
White oak – PVAc – borax	10.6	D	24.8
White oak – D-VTKA – control	10.0	D	–
Chestnut – D-VTKA – control	9.9	DE	–
Chestnut – D-VTKA – borax	8.6	E	12.9
Chestnut – D-VTKA – zinc chloride	8.5	E	13.3
White oak – D-VTKA – borax	6.4	F	35.5
White oak – D-VTKA – zinc chloride	6.2	F	37.6

H.G., homogeneity group.

TABLE VI
Average Bonding Strength Related to Wood Material Type and Impregnating Materials (N/mm^2)

	White oak (N/mm^2)	H.G.	Decrease (%)	Chestnut (N/mm^2)	H.G.	Decrease (%)
Control	12.1		–	12.6		–
Borax	8.5	A	29.7	10.8	B	14.2
Zinc chloride	8.5	A	29.7	11.3	C	10.3

multiple variance analyses with regard to the effects of impregnating materials and adhesive types are given in Table IV. The bonding strength of white oak samples, which have higher density than chesnut, is higher than chesnut samples.

The highest bonding strength was obtained in control samples. The results indicated that the impregnating materials decreased the bonding strength values. In literature, acidic fire reterdants can catalyze dehydration of glucose units and depolimerization of cellulose.[15] Thus, they cause a loss in strength properties due to wood fiber network degradation. In our study, reductions compared with the untreared specimens in bonding strength decreased as 37.61% for white oak.[16] Besides, it can be pointed out that longer immersion periods during the impregnating (by the $ZnCl_2$ pressing method) might have decreased the bonding strength of the adhesives. In a similar study, it was stated that the impregnating material could prevent the creation of sufficient association between the bonding surface and adhesive, causing the decrease of bonding strength.[17,18] Compared with the types of adhesives, the highest bonding strength was obtained in control samples as 14.86 N/mm^2. But, PVAc adhesive gave higher bonding strength than D-VTKA adhesive as 9.98 N/mm^2.

The difference between groups in accordance with the effect of variance sources on the bonding strength was significant (5%). The Duncan test results used to determine the importance of the differences between the groups are given in Table V. And also, the differences between the wood spesies, adhesive types and impregnating materials are given in Tables VI and VII.

TABLE VII
Average Bonding Strength in Accordance with Adhesive Type and Impregnating Materials (N/mm^2)

	PVAc (N/mm^2)	H.G.	Decrease (%)	D-VTKA (N/mm^2)	H.G.	Decrease (%)
Control	14.86	A	–	9.98	D	–
Borax	12.39	B	20.5	7.55	E	24.3
Zinc chloride	11.81	C	16.6	7.43	F	25.5

CONCLUSIONS

In early studies, it was stated that the impregnating chemicals did not affect on the bonding strength of some adhesives.[18–21] However, it was observed that the impregnating chemicals importantly affected the bonding strength of adhesives in the present study. For this purpose, in this study, it was aimed to determine the validity of this hypothesis, and experimental method was applied for this study.

The highest density was obtained with $ZnCl_2$ solution. This is because of that the vacuum-impregne-vacuum impregnating method and the excessive solution density might cause the density to increase. Retention quantities and ratios at long term dipping were found to be significantly high. In other words, the retention amount in chestnut was found in sufficient levels whereas in white oak it was higher than it was expected. The highest value of bonding strength was obtained from control samples. This can be interpreted that impregnating solutions of being crystal structure decreased bonding strength. The PVAc adhesive gave the best result for the control samples treated with impregnating materials. The weakness of bonding strength bonded with D-VTKA glue may be because of negative effect of salts in impregnating solution. Consequently, an evaluation of the bonding strength indicates that white oak and PVAc adhesive gave better results in the test samples. White oak and PVAc adhesive could be proposed for wood industry and furniture elements produced by massive wood materials.

This study was made as a M.Sc. Thesis by Oktay OKÇU in the Graduate School of Natural and Applied Sciences, Zonguldak Karaelmas University, Zonguldak 2006 [in Turkish].

References

1. Erten, P. The Main Techniques Used for Protecting of Wood Material; Center of National Production Publishers: Turkey, 1988; pp 127–130.
2. Sheard, L. Protecting of Wood Material: Valid Practices Reseources, Center of National Production Publishers: Turkey, 1988; pp 24–30, 338.
3. Özçifçi, A. Ph.D. Thesis, G.U. Institute of Science and Technology, Turkey, 2001.
4. Stevens, W. C.; Turner, N. Wood Bending Handbook; The Stationery Office HMSO Publisher: England, 1974; pp 90–110.
5. Bozkurt, Y.; Erdin, N. Wood Technology; I.U. Forest Faculty, Kale Press: Turkey, 1997; pp 237–345, 3998.
6. Dilik, T. Ph.D. Thesis, I.U. Institute of Science and Technology, Turkey, 1997.
7. Eckelman, C. A. Potential Uses of Laminated Veneer Lumber in Furniture; Department of Forestry and Natural Resources, Purdue University, Forest Products Society: West Lafeyette, USA, 1993; Vol. 43, pp 19–24.
8. Producer Firm Text, Polisan Dilovas1-Gebze. Instruction Manual; Kocaeli, Turkey, 1999.
9. ASTM-D 1413. Annual Book of ASTM Standards, 452, 2007.
10. TS 5724. Protecting of Wood—Determination of amount of Bo, Cu, Cr and Ar Chemicals in Water Based Impregnating Materials and Impregnated Wood, Turkish Standards Institute, 1988.
11. TS 2471. Determination of Relative Humudity for Physical and Mechanical Tests in the Wood Materials, Turkish Standards Institute, 1976.
12. TS 2472. Determination Volume and Weight for Physical and Mechanical Tests, Turkish Standards Institute, 1976.
13. EN 204. Non-structural Adhesives for Joining of Wood and Derived Timber Product, British Standards, 1991.
14. BS EN 205. Adhesives for Non-structural Applications—Determination of Tensile Shear Strenght of Lap Joints, Turkish Standards Institute, 1991.
15. LeVan, S.; Winandy, J. E. Wood Fiber Sci 1990, 22, 113.
16. Colakoglu, G.; Colak, S.; Aydin, I.; Yildiz, U. C.; Yildiz, S. Silva Fennica 2003, 37, 505.
17. Örs, Y.; Atar, M.; Keskin, H. Int J Adhes Adhesives 2004, 24, 287.
18. Özçifçi, A. Build Environ 2007, 42, 1510.
19. Celebi, G.; Kilic, M. Construct Build Mater 2007, 21, 894.
20. Celebi, G.; Ilce, A. C.; Kilic, M.; Ozkaya, K. J Appl Polym Sci 2006, 101, 1943.
21. Kilic, M.; Celebi, G. J Appl Polym Sci 2005, 102, 3673.