

Effects of Impregnation Materials on Combustion Properties of Laminated Veneer Lumber Obtained from European Oak (*Quercus petraea* Liebl.) and Lombardy Poplar (*Populus nigra* L.)

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ABSTRACT: The aim of this study was to investigate the impact of impregnation with boron compounds borax (Bx), boric acid (Bx), Bx + Ba (wt : wt 50 : 50%), Imersol-aqua (Ia) and Timbercare-aqua (Ta) on combustion properties of the laminated veneer lumber (LVL) obtained from European oak (*Quercus petraea* Liebl.) and Lombardy poplar (*Populus nigra* L.) woods, impregnated with boron compounds, Imersol-Aqua, and Timbercare-Aqua according to ASTM D 1413-76-99 and directions of the manufacturer. The LVL samples were prepared in the form of five layers, of 3-mm thickness from the oak and poplar veneers according to TS EN 386. Combustion properties of the LVL test samples were determined according to ASTM D 160-50. Considering the interaction of combustion type and impregnation materials, the highest

flame source combustion (FSC) and without flame source combustion (WFSC) temperatures were found in control test samples, but the lowest values in samples impregnated with Bx and Ia solutions. Consequently, borax in FSC and Imersol-Aqua in WFSC showed a decreasing impact on combustion properties of the LVL, produced combination of European oak and Lombardy poplar veneers, and bonded with Desmodur-VTKA. In consequence, the LVL impregnated with borax and Imersol-Aqua could be recommended as a flame retardance construction material where required. © 2007 Wiley Periodicals, Inc. *J Appl Polym Sci* 105: 1766–1773, 2007

Key words: flame retardance; density; compounding; adhesive; structure

INTRODUCTION

Wood material burns by itself when its temperature reaches 275°C or with an inflammable material at lower temperatures. Wood materials have better properties than many construction materials, but it is impossible to make it wholly incombustible. It is obvious that processing wood with some chemical treatments increase fire resistance and combustion properties. For this purpose, ammonium sulfate, ammonium chloride, borax, boric acid, phosphoric acid, etc. are used mostly.¹

Massive constructions and furnitures, coated only with paint and varnish, have surface protection only for 2 years. So, varnishing and painting after the impregnation is important for long-term utilization against biotic and abiotic effects, photochemical degradation, dimensional changes, biological factors, and fire.²

Painting and varnishing with water-repellent chemicals after impregnating with boron compounds makes the wood more resistant to environmental con-

ditions.³ Impregnating with the solution of copper, chrome, and salt makes wood more resistant to environmental effects.⁴ For combustion properties, the most suitable impregnated wood material is 15% solution of paraffine + boric acid + borax.⁵

Uysal declared that diammonium phosphate was the most effective fire-retardant chemical in laminated veneer lumber (LVL), with phenol formaldehyde (PF) and poly(vinylacetate) (PVAc) adhesives. Because it diminishes combustion the most, LVL made of Scotch pine with PF or PVAc adhesives by using pressure-vacuum method and impregnated with diammonium phosphate can be recommended as a fire-resistant construction material where required.⁶

It was assessed that, the effects of impregnation materials, sodium perborate, sodium tetraborate, Imersol-WR 2000, and Tanalith-CBC, on combustion properties of three-ply laminated wood material produced from Uludağ fir (*Abies bornmülleriana* M.) were investigated. As a result, the highest mass reduction in massive wood samples impregnated with Tanalith-CBC was determined.⁷

In another research, it was carried out to determine the bonding strength of PF and melamine-formaldehyde adhesives to impregnated wood materials. For this purpose, pine (*Pinus brutia* Ten) and elm (*Ulmus*

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compestris L.) woods were impregnated with boron compounds, diammonium phosphate, and Tanalith-C 3310 using the vacuum method according to ASTM D 1413. The effects of wood species, impregnating material, and type of adhesive on the bonding strength were determined. The highest shear strength (11.09 N mm^{-2}) was obtained from elm wood control (i.e., without any impregnating materials) samples with melamine-formaldehyde; thus, the impregnation process negatively affected the adhesive bonding strength.⁸

The investigation of Kolmann yielded pertinent information that the thermal degradation of the hardwood species is lower than sapwood species, for hardwood contains more sensitive pentozans.⁹

Goldstein declared that the lignin of spruce started to degrade at $130\text{--}145^\circ\text{C}$ and its cellulose at $156\text{--}170^\circ\text{C}$. When the dust of beech wood was held at 160°C for 28 days, it lost its cellulose at 80% and within 14 days it lost its lignin at 2–3%.¹⁰

Uysal and Ozciftci¹¹ carried out three-layered LVL, produced from PVAc adhesive and lime-tree and consisting of different core ply, and tested according to the procedure of ASTM E 69 combustion standards. The highest amount of ash and unburned pieces were obtained in LVL consisting of lime-tree.

Yalinkılıç and Ors¹² studied impregnation with boron compounds and the groups of the PEG-400 of Douglas (*Pseudotsuga menziesii* Franco) wood, the test samples were applied to the combustion tests. Although the groups of the PEG-400 had a negative impact on combustion; however, boron compounds were shown to give more effective results.

This study was performed to determine the impact of impregnation with boron compounds, Imersol-Aqua and Timbercare-Aqua, on combustion properties of the LVL-produced combination of European oak and lombardy poplar veneers bonded with Desmodur-VTKA adhesive.

MATERIALS AND METHODS

Materials

Wood materials

European oak (*Quercus petraea* Liebl.) and lombardy poplar (*Populus nigra* L.) woods were selected as test materials because of wide usage of industry. Special emphasis was given for the selection of wood materials that are nondeficient, proper, knotless, normally grown (without reaction wood, decay and mushroom damages) according to TS 2476.¹³

Impregnation materials

Boron compounds. Boric acid and borax are obtained from Etibank-Bandırma (Turkey) Borax and Acid Factory. Properties of boric acid (H_3BO_3) is 56.30%

$1/2\text{B}_2\text{O}_3$, 43.70% H_2O with a molecular weight 61.84, density 1.435 g cm^{-3} and melting point 171°C . Borax ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$) 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} , and melting point 741°C .¹⁴

Imersol-aqua. In this study, Imersol-aqua was supplied from Hemel-Hickson Timber Products, Istanbul. I_{AQUA} is nonflammable, odorless, fluent, water-based, completely soluble in water, and noncorrosive, with a pH value of 7 and a density of 1.03 g cm^{-3} . It is available as ready-made solution. It contains 0.5% w/w tebuconazole, 0.5% w/w propiconazole, 1% w/w 3-iodo-2-propynyl-butyl carbonate, and 0.5% w/w cypermethrin. Before the application of Imersol-aqua on the wood material, all kinds of drilling, cutting, turning, and milling operations should be completed and the relative humidity should be in equilibrium with the test environment. The impregnated wood was left to dry for at least 24 h. The wood material can be painted, varnished, or glued after it is fully dried.¹⁵

Timbercare-aqua. Timbercare-aqua was also supplied from Hemel-Hickson Timber Products, Istanbul. Timbercare-aqua is nonflammable, odorless, fluent, water-based and completely soluble in water, and noncorrosive, with a pH value of 7. It is available as ready-made solution. After the application of Timbercare-aqua, surface should be painted by a UV-resistant coating. Before painting, it should be kept for 24 h till the timber gets dried. Before the application of Timbercare-aqua on the wood material, all kinds of manufacturing operations should be completed and the relative humidity should be in equilibrium with the test environment.¹⁵

Adhesive

Desmodur-VTKA adhesive usually has been found preferable for the assembly process in the woodworking industry. It is a one-component (without any solvent), polyurethane-based and moisture-cured adhesive. Bonding surface should be clean, dry, dust- and oil-free. Dry surfaces should be moisturized so as to increase hardening speed of the glue. Adhesive is directly applied to one of the surfaces, and bonding process is conducted at $(20 \pm 2)^\circ\text{C}$ and $(65 \pm 5)\%$ relative humidity conditions. Polyurethane glue has a pH of about 7 and a viscosity of $5500\text{--}7500 \text{ mPa s}$ at $(25 \pm 2)^\circ\text{C}$. Its density is $1.11 \pm 0.02 \text{ g cm}^{-3}$, the period of solidification at $(20 \pm 2)^\circ\text{C}$ with $(65 \pm 5)\%$ relative humidity is 24 h. It is recommended that Desmodur-VTKA adhesive should be applied on one surface at $\sim 180 \text{ g m}^{-2}$. It solidifies in 30 min according to the guidelines given by the producer.¹⁶

Method

Determination of density

The densities of laminated wood samples were determined according to TS 2472.¹⁷ For gathering the air-

TABLE I
Impregnation Test Plan

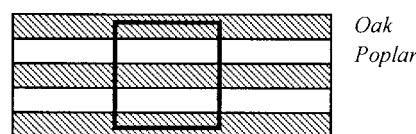
Test no	Impregnation materials	Sample humidity (%)	Solution concentration (%)	Solvent
1	Control (Co)	12	–	–
2	Boric acid (Ba)	12	5.5	Pure water
3	Borax (Bx)	12	5.5	Pure water
4	Ba+Bx	12	5.5	Pure water
5	Imersol-aqua (Ia)	12	100	–
6	Timbercare-aqua (Ta)	12	100	–

dry density, the test samples with a dimension of $20 \times 30 \times 30 \text{ mm}^3$ were kept under the conditions of $(20 \pm 2)^\circ\text{C}$ and $(65 \pm 5)\%$ relative humidity until they reached a constant weight. The weights were measured with an analytic scale of $\pm 0.01 \text{ g}$ sensitivity. Afterward, the dimensions were measured with a digital compass of $\pm 0.01 \text{ mm}$ sensitivity. The air-dried densities (δ_{12}) of the samples were calculated by the following formula 1:

$$\delta_{12}(\text{g cm}^{-3}) = \frac{W_{12}}{V_{12}} \quad (1)$$

where W_{12} is the air-dry weight (g) and V_{12} is the volume (cm^3) at air-dry conditions.

The samples were kept at the temperature of $(103 \pm 2)^\circ\text{C}$ in the drying oven until they reached a stable weight of oven-dry density. Afterward, oven-dried samples were cooled in the desiccators containing calcium chloride (CaCl_2). Then, they were weighted on a scale of $\pm 0.01 \text{ g}$ sensitivity balance, and their dimensions were measured with a digital compass of $\pm 0.01 \text{ mm}$. The volumes of the samples were determined by stereometric method, and the densities (δ_o) were calculated by the following formula 2:



13x13x76 mm
(The thickness of label is 3 mm)

Figure 1 Combustion test sample (scale: 1/1).

$$\delta_o(\text{gcm}^{-3}) = \frac{W_o}{V_o} \quad (2)$$

where W_o is the oven-dry weight (g) and V_o is the oven-dry volume (cm^3) of the wood material.

Determination of moisture content

The moisture content of the test samples before and after impregnation process was determined according to TS 2471.¹⁸ Thus, the samples with a dimension of $20 \times 20 \times 20 \text{ mm}^3$ were weighted and dried at $(103 \pm 2)^\circ\text{C}$ in an oven till they reach a constant weight. Then, the samples were cooled in desiccator containing calcium chloride (CaCl_2) and weighted with an analytic scale of 0.01 g sensitivity. The moisture content of the samples (h) was calculated by the following formula 3:

$$h = \frac{W_r - W_o}{W_o} \times 100 \quad (3)$$

where W_r is the initial weight of the samples (g) and W_o is the final dry weight (oven-dry) of the samples (g).

Preparation of test samples

Laminated wood samples with the dimensions of $25 \times 25 \times 500 \text{ mm}^3$ were cut from the sapwood parts of solid woods and conditioned at a temperature of $(20$

TABLE II
Retention Quantities of Impregnation Materials (kg m^{-3})

Wood materials	Statistics values	Ba	Bx	Ba+Bx	Ia	Ta
European oak	X	3.381	3.853	4.032	63.104	44.196
	SD	0.311687343	0.336245446	0.436298063	5.72520951	3.43224766
	V	0.107943333	0.125623333	0.211506667	36.4200266	13.0892488
	Min.	2.95	3.34	3.37	53.65	38.66
	Max.	3.89	4.32	4.99	72.09	49.62
Lombardy poplar	X	69.668	76.793	67.133	84.060	58.351
	SD	6.555078642	6.515030391	10.4742542	6.84444154	6.95933394
	V	47.74339556	47.16180111	121.900001	52.0515333	53.8136988
	Min.	55.83	65.58	49.68	74.99	48.68
	Max.	79.85	85.29	88.35	92.68	69.25

X, mean; SD, standard deviation; V, variance; Min, minimum; Max, maximum; Ba, boric acid; Bx, borax; Ba+Bx, boric acid + borax; Ia, Imersol-aqua; Ta, Timbercare-aqua.

TABLE III
The Impact of Wood Types and Impregnation Materials on Retention

Source	SS	DF	MS	F value	SIG ^a
Between groups	91847.292	9	10205.255	273.875	0.0000
Within groups	3353.623	90	37.262		
Total	95200.915	99			

^a $P < 0.05$; SS, sum of squares; DF, degrees of freedom; MS, mean square; SIG, significance.

± 2)°C and (65 \pm 5)% relative humidity for 3 months, until they reached an equilibrium in moisture distribution. They were impregnated with boron compound by vacuum method by using Imersol-Aqua by dipping method and with Timbercare-Aqua by brushing method according to the procedure of the ASTM D 1413-76-99 standards¹⁹ and directions of the manufacturer. Accordingly, the samples of vacuum method were exposed to 760 mmHg prevacuum for 60 min, and then they were held in a solution under normal atmospheric pressure for 60 min to allow the diffusion of boron compounds. The samples of dipping method were dipped for 2 h for medium-term dipping in the impregnation pool. The specifications of Imersol-aqua solution were determined before and after the process. The samples of brushing method were brushed with Timbercare-aqua solution by using a brush according to the producers' definition. The brushing process was performed twice with a period of 3–4 h.

The processes were carried out at (20 \pm 2)°C. Retention of impregnation chemical (R) was calculated by the following formula 4:

$$R(10^3 \text{kgm}^{-3}) = \frac{GC}{V} (G = T_2 - T_1) \quad (4)$$

where G is the amount of impregnation solution absorbed by the sample, T_2 the sample weight after the impregnation, T_1 the sample weight before the impregnation, C the concentration (%) of the impregnation solution, and V is the volume of the samples. Impregnated test samples were kept at a temperature of (20 \pm 2)°C and (65 \pm 3)% humidity content until

TABLE IV
Retention Quantities as a Result of Duncan Test

Impregnated wood materials	Subset for $\alpha = 0.05$						
	1	2	3	4	5	6	7
O + Ba	3.381						
O + Bx	3.853						
O + (Ba+Bx)	4.032						
O + Ta		44.196					
P + Ta			58.351				
O + Ia			63.104	63.104			
P + (Ba+Bx)				67.133	67.133		
P + Ba					69.668		
P + Bx						76.793	
P + Ia							84.060
SIG	0.824	1.000	0.085	0.143	0.356	1.000	1.000

Means for groups in homogeneous subsets are displayed. Uses harmonic mean sample size N : 10; O, oak; P, poplar; Ba, borax; Ba, boric acid; Ta, Timbercare-aqua; Ia, Imersol-aqua.

they reach a stable weight. Impregnation test plan is given in Table I.

The LVLs were prepared in the form of five layers from European oak and lombardy poplar veneers bonded with Desmodur-VTKA adhesive according to TS EN 386.²⁰ For this purpose, veneers with 3 mm thickness were cut from air-density impregnated lumbers. The adhesive was spread to one surface of veneer by using a roll. The spreading rate of adhesive was $\sim 180 \text{ g m}^{-2}$. The spreading rate was calculated by weighing each veneer before and after bonding. Pressure of 0.8 N mm^{-2} was applied on the bonding line according to the adhesive producers' definition. The solidification time was ~ 30 min. The LVL samples were kept at a temperature of (20 \pm 2)°C and (65 \pm 5)% relative humidity until it reaches to a constant weight. Combustion test sample dimensions of $13 \times 13 \times 76 \text{ mm}^3$ were prepared from the LVLs (Fig. 1) according to ASTM E 160.²¹

Combustion test

Combustion tests were carried out according to ASTM E 160-50 standards in combustion test device. Rela-

TABLE V
Oven-Dry Densities of Impregnated and LVL Samples (g cm^{-3})

Statistics values	Co	Ba	Bx	Ba + Bx	Ia	Ta
X	0.506	0.517	0.519	0.520	0.543	0.536
SD	0.00620080	0.00795550	0.00681542	0.01022986	0.00986103	0.01080555
V	0.00004272	0.00007032	0.00005161	0.00011627	0.00010804	0.00012973
Min.	0.492	0.504	0.512	0.509	0.528	0.516
Max.	0.517	0.531	0.534	0.547	0.562	0.556

X, mean; SD, standard deviation; V, variance; Min, minimum; Max, maximum; Co, control; Ba, boric acid; Bx, borax; Ba+Bx, boric acid + borax; Ia, Imersol-aqua; Ta, Timbercare-aqua.

TABLE VI
The Impact of Impregnation Materials on Oven-Dry Density of Test Samples

Source	SS	DF	MS	F value	SIG ^a
Between groups	0.009	5	0.002	21.086	0.0000
Within groups	0.005	54	0.000		
Total	0.014	59			

^a $P < 0.05$; SS, sum of squares; DF, degrees of freedom; MS, mean square; SIG, significance.

tively, before combustion test, impregnated and laminated samples were conditioned at 27°C and 30% relative humidity in a conditioning room, until it reaches 7% relative humidity. Samples were weighted before combustion tests. Fire distance from maker type outlet at the lower bound of funnel was fixed to 25 ± 1.3 cm. When the device was empty the gas pressure was fixed to 0.5 kg cm^{-2} . During burning, the temperature was set at $(315 \pm 8)^\circ\text{C}$ in the funnel. Flame source was centered below sample pile, and flame source combustion (FSC) was continued for 3 min. After extinguishing of flame source, without flame source combustion (WFSC) was carried out. Then the temperature changes of combustion ($^\circ\text{C}$) were determined by using digital thermometer.

Statistical analyses

The impact of impregnation with boron compounds, Imersol-aqua and Timbercare-aqua on the combustion properties of LVL-produced combination of European oak and black poplar veneers bonded with Desmodur-VTKA, was analyzed by analysis of variance (ANOVA). When the differences between groups were found to be significant, Duncan test was used to determine the differences between means at prescribed level of $\alpha = 0.05$. In this research, one type of wood material, two types of combustion, five types of impregnation materials and one control sample, and one adhesive of lamination were selected. Relatively, prepared sum of samples was 144. Statistical values (ANOVA, Duncan test, mean, deviation of standard, variance, minimum and maximum values) were calculated by the SPSS 13.00.

TABLE VIII
Air-Dry Densities of Impregnated and LVL Samples (g cm^{-3})

Statistics values	Co	Ba	Bx	Ba + Bx	Ia	Ta
X	0.537	0.546	0.551	0.551	0.568	0.564
SD	0.012562245	0.01670449	0.016229911	0.011402193	0.012083046	0.015053571
V	0.000175344	0.000310044	0.000292678	0.000144456	0.000162222	0.000251789
Min.	0.519	0.524	0.525	0.536	0.548	0.537
Max.	0.552	0.572	0.586	0.571	0.592	0.585

X, mean; SD, standard deviation; V, variance; Min, minimum; Max, maximum; Co, control; Ba, boric acid; Bx, borax; Ba+Bx, boric acid + borax; Ia, Imersol-aqua; Ta, Timbercare-aqua.

TABLE VII
Oven-Dry Densities as a Result of Duncan Test

Impregnation chemicals	N	Subset for $\alpha = 0.05$			
		1	2	3	4
Co	10	0.506			
Ba	10		0.517		
Bx	10		0.519		
Ba + Bx	10		0.520		
Ta	10			0.536	
Ia	10				0.543
SIG		1.000	0.447	1.000	1.000

Means for groups in homogeneous subsets are displayed. Uses harmonic mean sample size N , 10.

RESULTS AND DISCUSSION

Retention quantities

Results of retention tests were summarized by using descriptive statistics, such as the maximum, minimum, mean, standard deviation and variance. Retention quantities of impregnation chemicals are given in Table II. ANOVA of the impact of impregnation chemicals on retention quantities of LVL is given in Table III.

According to ANOVA, the differences between groups were found to be significant ($F_{9;90} = 273.875$, $P < 0.05$). Duncan test was used to determine the differences between means at prescribed level of $\alpha = 0.05$, and the results of Duncan Test are shown in Table IV.

According to Duncan test results, highest retention amount was obtained in Poplar + Imersol-aqua and the lowest was in Oak + Boron compounds wood samples. The highest retention amount obtained in black poplar could be attributable to the impact of permeability. The lowest retention amounts were found in European oak. This may be due to tyloses in oak wood samples.

Oven-dry density

Statistical values for the oven-dry density of impregnated LVL produced oak and poplar veneers combination-bonded with Desmodur-VTKA are given in

TABLE IX
The Impact of Impregnation Materials on Air-Dry Density of Test Samples

Source	SS	DF	MS	F value	SIG ^a
Between groups	0.070	5	0.001	6.077	0.0000
Within groups	0.012	54	0.000		
Total	0.019	59			

^a $P < 0.05$; SS, sum of squares; DF, degrees of freedom; MS, mean square; SIG, significance.

Table V. ANOVA of the impact of impregnation chemicals on oven-dry densities of LVL samples are presented in Table VI.

The differences between groups were found to be significant ($F_5; 54 = 21.086, P < 0.05$). Duncan test was used to determine the differences between means at prescribed level of $\alpha = 0.05$. The results of Duncan Test are displayed in Table VII.

As seen in Table VI, impregnated with Imersol-aqua LVL, test samples have the highest oven-dry density (0.543 g cm^{-3}). In contrast, un-impregnated LVL samples (0.506 g cm^{-3}) have the lowest oven-dry densities in all groups.

Air-dry density

The statistical values for the air-dry density of impregnated LVL test samples are given in Table VIII.

ANOVA of the impact of impregnation chemicals on air-dry densities of LVL samples are presented in Table IX.

The differences between groups were found to be significant ($F_5; 54 = 6.077, P < 0.05$). Duncan test was used to determine the differences between means at prescribed level of $\alpha = 0.05$, and the results of Duncan Test are displayed in Table X.

Table X shows that impregnated with Imersol-aqua test samples (0.568 g cm^{-3}) have the highest air-dry density. In contrast, un-impregnated LVL control

TABLE X
Air-Dry Densities as a Result of Duncan Test

Impregnation chemicals	N	Subset for $\alpha = 0.05$			
		1	2	3	4
Co	10	0.537			
Ba	10	0.546			
Ba + Bx	10	0.551		0.551	
Bx	10	0.551		0.551	
Ta	10	0.565			
Ia	10	0.568			
SIG		1.000	0.494	0.062	1.000

Means for groups in homogeneous subsets are displayed. Uses harmonic mean sample size $N, 10$.

samples (0.537 g cm^{-3}) have the lowest air-dry densities in all groups.

The air-dry and oven-dry densities of impregnated samples increased with respect to un-impregnated samples. Impregnated with Imersol-aqua samples densities were increased compared with the impregnated boron compounds and Timbercare-aqua samples. This result may be due to the more penetration of impregnation solution into the wood with the extension of time.

Combustion properties

Results of combustion tests were summarized by using descriptive statistics such as the maximum, minimum, mean, standard deviation, and variance. Combustion test results of impregnated LVL samples are given in Table XI.

Average temperature values of different combustion type materials are given in Table XII.

Results of ANOVA, for impact of combustion type and impregnation materials on combustion temperatures of LVL samples, are given in Table XIII.

The differences between groups were found to be significant ($F_{11}; 132 = 6.320, P < 0.05$). Duncan test was used to determine the differences between means

TABLE XI
Combustion Values of Impregnated LVL Test Samples ($^{\circ}\text{C}$)

Types of combustion	Statistics values	Co	Ba	Bx	Ba + Bx	Ia	Ta
FSC	X	575.583	494.500	342.833	464.250	463.583	482.750
	SD	54.785123	74.689914	47.400480	65.448612	100.81787	83.915756
	V	3274.2651	6085.7272	2451.0606	4672.9318	11088.265	7682.0227
	Min.	486	305	275	366	303	356
	Max.	629	577	439	555	584	586
WFSC	X	510.416	458.416	401.083	420.083	353.916	473.750
	SD	77.752232	95.600260	96.258729	99.842758	95.666485	118.5004
	V	6594.9924	9970.2651	10108.083	10874.810	9984.0833	15318.931
	Min.	426	296	241	302	229	290
	Max.	635	561	524	590	575	634

FSC, flame source combustion; WFSC, without flame source combustion; Co, control; Ba, boric acid; Bx, borax; Ba+Bx, boric acid + borax; Ia, Imersol-aqua; Ta, Timbercare-aqua.

TABLE XII
Average Temperature Values of Different Combustion Type and Materials

	Temperature ^a (°C)
Types of combustion ^b	
Flame source combustion (FSC)	470.583 A
Without flame source combustion (WFSC)	436.278 B
Impregnation materials ^c	
Control (Co)	543.000 A
Boric acid (Ba)	476.458 B
Borax (Bx)	371.958 D
Boric acid + Borax (Ba + Bx)	442.167 BC
Imersol-aqua (Ia)	408.750 CD
Timbercare-aqua (Ta)	478.250 B

^a Different letters in a column refers to significant differences among types of processes and materials at 0.05 confidence level.

^b LSD_{0.5}, 29.79.

^c LSD_{0.5}, 51.59.

TABLE XIII
Impact of Combustion Type, Impregnation Materials on Combustion Temperatures

Source	SS	DF	MS	F value	SIG ^a
Between groups	568319.472	11	51665.407	6.320	0.0000
Within groups	1079159.833	132	8175.453		
Total	1647479.306	143			

^a $P < 0.05$; SS, sum of squares; DF, degrees of freedom; MS, mean square; SIG, significance.

at prescribed level of $\alpha = 0.05$. The results of Duncan Test are displayed in Table XIV.

In the interaction of type of combustion and impregnation materials, the highest FSC and WFSC temperatures were found in control samples, but the lowest in borax and Imersol-Aqua samples (Fig. 2).

CONCLUSIONS

Retention amount of impregnation material was found to be the highest in Imersol-Aqua and the lowest in boron compounds. The reason for the higher amount of retention with Imersol-Aqua might be due to high concentration of solution. For that reason, it can be said that a type of impregnation chemical is effective on the amount of retention. In the research, the highest obtained retention amount in Lombardy poplar + Imersol-Aqua could be attributable to the impact of permeability. The lowest retention amounts were found in European oak. In a similar research, it was reported that in the impregnation of oak the retention decreased with the increase in impregnation period.²² This may be due to tyloses in oak wood samples.

FSC temperatures in impregnation process were lower 14.087% in Ba, 40.437% in Bx, 19.342% in Ba +

TABLE XIV
Average Temperature Values for the Combination Process and Materials

Combination	N	Subset for $\alpha = 0.05$				
		1	2	3	4	5
FC + Bx	10	342.83				
WFC + Ia	10	353.92				
WFC + Bx	10		401.08			
WFC + (Ba+Bx)	10		420.08	420.08		
WFC + Ba	10		458.42	458.42	458.42	
FC + Ia	10		463.58	463.58	463.58	
FC + (Ba+Bx)			464.25	464.25	464.25	
WFC + Ta			473.75	473.75	473.75	510.42
FC + Ta			482.75	482.75	482.75	
FC + Ba				494.50	494.50	
WFC + Co						510.42
FC + Co						575.58
SIG		0.053	0.059	0.084	0.133	0.062

Means for groups in homogeneous subsets are displayed. Uses harmonic mean sample size N , 12; FSC, flame source combustion; WFSC, without flame source combustion; Co, control; Ba, boric acid; Bx, borax; Ba+Bx, boric acid + borax; Ia, Imersol-aqua; Ta, Timbercare-aqua.

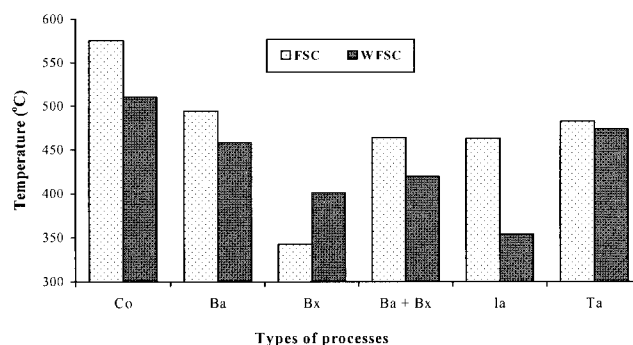


Figure 2 Combustion temperature changes of impregnated LVL test samples.

Bx, 19.458% in Ia, 16.128% in Ta than un-impregnated control samples. WFSC temperatures in impregnation process were lower 10.187% in Ba, 21.420% in Bx, and 17.697% in Ba + Bx, 30.661% in Ia, 7.183% in Ta than control samples.

Considering the interaction of combustion type and impregnation materials, the highest FSC and WFSC temperatures were found in control test samples, but the lowest values in borax and Imersol-Aqua samples. Indeed, after the treatment with boron compounds, combustion temperature of Uludağ fir (*Abies Bornmülleriana* L.) wood was decreased.⁷

Consequently, borax in FSC and Imersol-Aqua in WFSC showed a decreasing impact on combustion properties of the LVL, bonded with Desmodur-VTKA. In consequence, the LVL impregnated with borax and Imersol-Aqua could be recommended as a flame retardance construction material where required.

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