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Effects of Impregnation Solutions on Weight Loss during Combustion of Laminated Veneer Lumber

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ABSTRACT

The aim of this study is to investigate the effects of impregnation chemicals on the weight loss during combustion of Laminated Veneer Lumber (LVL) obtained from combination of Oriental beech + Lombardy poplar and European oak + Lombardy poplar woods, impregnated with Borax (Bx), Boric acid (Ba), Bx+Ba (wt:wt 50:50%), Imersol-aqua and Timbercare-aqua according to ASTM D 1413. The LVL samples were prepared in the form of five layers, 3 mm thickness from the beech, oak and poplar veneers bonded with Desmodur-VTKA and Poly(vinyl acetate) adhesives, according to TS EN 386. The weight loss during combustion of the LVL test samples was determined according to ASTM E 160. Consequently, the weight loss percentage was the highest in beech-poplar combination processed with Imersol-aqua and D_{VTKA} and the lowest in oak-poplar combination, Ba+Bx and PVAc adhesive. In the interaction of the wood materials, impregnation chemicals and adhesive types, it was the highest in beech-poplar combination + Timbarecare-aqua + D_{VTKA} and the lowest in beech-poplar combination + (Ba+Bx) + PVAc. As a result, it can be said that the type of impregnation material has a first degree efficacy and wood material have second degree efficacy on the weight loss. Thus, the weight loss was high in beech-poplar combination impregnated with Ta but low in the same wood material impregnated with Ba+Bx. Accordingly, for places which has fire risk, usage of LVL wood material impregnated with boron compounds would be advantageous.

Key Words: Combustion, Impregnation Solutions, Weight Loss, Laminated Veneer.

1. INTRODUCTION

Wood and wood-based materials are mainly composed of carbon and hydrogen. For this reason, they are combustible [1]. When heated, wood burns by producing flammable volatiles that may ignite. For wood to spontaneously combust, the temperature must be raised to 275°C. However, if there is a flame source, it can become flammable at lower temperature [2]. For wood ignition; oxygen (O_2), flame source and flammable material are necessary. However, wood has excellent natural fire resistance as a result of its remarkably low thermal conductivity and the fact that wood char is formed when wood is burned. In order to reduce flammability and provide safety, wood is treated with fire-retardant chemicals. In other words, the combustibility of wood may be reduced with flame-retardants or fire-retardants [3 and 4].

Wood materials have better properties than many construction materials, but it is impossible to make their wholly incombustible. It is obvious that, processing wood with some chemical treatments increase fire resistance and combustion properties. For this purpose, ammonium sulphate, ammonium chloride, borax, boric acid and phosphoric acid etc. are used mostly [5].

Massive constructions and furnitures exposed outside, coated only with paint and varnish, have surface protection only for two 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 [6].

Painting and varnishing with water-repellent chemicals after impregnating with boron compounds makes the wood more resistant to environmental conditions [7]. Impregnating with the solution of copper, chrome and

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salt makes wood more resistant to environmental effects [8]. For combustion properties, the most suitable impregnated wood material is 15 % solution of paraphine + boric acid + borax [9].

Uysal declared that, Diammonium phosphate was the most effective fire-retardant chemical in Laminated Veneer Lumber (LVL) bonded with phenol-formaldehyde (PF) and poly(vinyl acetate) (PVAc) adhesives. Because it diminishes combustion the most, LVL made of Scotch pine bonded 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 [10].

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 were investigated. As a result, the highest mass reduction in massive wood samples impregnated with Tanalith-CBC was determined [11]. In another research, it was carried out to determine the bonding strength of phenol-formaldehyde and melamine-formaldehyde adhesives to impregnated wood materials. For this purpose, pine and elm 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 (nonimplegnated materials) samples with melamine-formaldehyde; thus, the impregnation process negatively affected the adhesive bonding strength [12].

The investigation of Kolmann yielded pertinent information on the thermal degradation of the hardwood species is lower than sapwood species for hardwood contains more sensitive pentozans [13].

Goldstain declared that the lignin of spruce started degradation at 130-145 °C and its cellulose at 156-170° C. When the dust of beech wood was held at 160 °C for 28 days, it lost its cellulose as 80 % and within 14 days it lost its lignin as 2 - 3 % [14].

Uysal and Ozcifci [15] carried out 3 layered LVL (laminated veneer lumber), 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.

Yalınkılıc and Ors [16] 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 effect on combustion however, boron compounds were shown more effective results.

This study was performed to determine the effects of impregnation chemicals on the weight loss during combustion of the LVL prepared from combination of beech + poplar and oak + poplar veneers, bonded with Desmodur-VTKA and PVAc adhesive.

2. MATERIAL AND METHOD

2.1. Material

2.1.1. Wood materials

Oriental beech (*Fagus orientalis* Lipsky)**,** European oak (*Quercus petraea* Liebl.) and Lombardy poplar (*Populus nigra* Lipsky) woods were selected as test materials because of wide usage of industry. Special emphasis was given for the selection of wood materials which are non-deficient, proper, knotless, normally grown (without reaction wood, decay and mushroom damages) according to TS 2476 [17].

2.1.2. Impregnation materials

Boron compounds (Boric acid, Borax)

Boric acid (Ba) and borax (Bx) are obtained from Etibank-Bandırma (Turkey) borax and Acid Factory. Properties of boric acid (H_3 B O_3) is 56.30% ½ B_2O_3 43.70% H_2O with a molecular weight 61.84, density 1.435 $g.cm^{-3}$ and melting point is 171 ^{0}C. Borax (Na_2 B_4 O_7 $5H_2O$) content is 21.28 % Na_2O 47.80% B_2O_3, 30.92% H_2O with a molecular weight 291.3, a density of 1.82 $g.cm^{-3}$, melting point is 741 ^{0}C [18].

Imersol-aqua

Imersol-aqua (Ia) was supplied from Hemel-Hickson Timber Products Co., Istanbul. Imersol-aqua is non-flammable, odorless, fluent, water based, completely soluble in water, no corrosive material 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 for drying at least 24 hours [19].

Timbercare-aqua

Timbercare-aqua (Ta) was also supplied from Hemel-Hickson Timber Products Ldt., Istanbul. Ta is non-flammable, odorless, fluent, water-based and completely soluble in water, no corrosive material 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 waited for 24 hours and be sure the timber is 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 [19].

2.1.3. Adhesives

Poly(vinyl acetate)

Poly(vinyl acetate) (P_{VAc}) is odorless, nonflammable adhesive. It can be used in cold temperatures and solidified quickly. Its application is very easy and does not damage the tools during the cutting process. However, P_{VAc} adhesive's mechanical resistance decreases with increasing heat. It loses bonding resistance capacity over 70 ^{o}C. On the condition that the adhesive is applied to only one surface, using 150 to 200 g.m^{-2} adhesive seems to be suitable. TS 3891 standard procedure was used for applying P_{VAc} adhesive. The density of P_{VAc} should be 1.1 g.cm^{-3}, the viscosity is 16.000 ± 3.000 mPa s; pH value and ash ratio should be 5 and 3 % respectively. A pressing time of 20 min for cold process and 2 min and 80 ºC are recommended with 6 to 15 % humidity for jointing process. After a hot-pressing process, the materials should be held until its normal temperature is reached [20].

Desmodur-VTKA (D_{VTKA})

Desmodur-VTKA (D_{VTKA} = Desmodur-Vinyl Trie Ketonol Acetate) 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 moisture 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±2 °C and 65±5 % relative humidity conditions. Polyurethane glue has a pH of about 7 and a viscosity of 5500-7500 mPa s at 25±2 ^{o}C. Its density is 1.11±0.02 g cm^{-3}, the period of solidification at 20±2 °C with 65±5 % relative humidity is 24 h. It is recommended that D_{VTKA} adhesive should be applied one surface approximately 180 g m^{-2}. It solidifies in 30 min. according to its producer [20].

P_{VAc} and D_{VTKA} adhesives were supplied POLISAN, a producer firm in Izmit, Turkey [21].

2.2. Method

The moisture content of test samples before and after the impregnation process was determined according to TS 2471 [22]. Thus, the samples with a dimension of 20x20x20 mm were weighted and then dried at 103±2 °C in an oven till they reach to a constant weight. Then, the samples were cooled in desicator containing calcium chloride (CaCl) and weighted with an analytic scale of 0.01g sensitivity. The moisture content of the samples (h) was calculated by the following formula 1:

$$h = \frac{Wr - Wo}{Wo} x\ 100\ \ g.g^{-1} \qquad (1)$$

Where, *Wr* is the initial weight of the samples (g) and *Wo* is the final dry weight (oven-dry) of the samples (g).

The air-dry density of laminated wood samples was determined according to TS 2472 [23]. For gathering the air-dry density, the test samples with a dimension of 20x30x30 mm were kept under the conditions of 20±2 ^{0}C and 65±5 % relative humidity until they reached to a constant weight. The weights were measured with an analytic scale of ±0.01g sensitivity. Afterwards, the dimensions were measured with a digital compass of ±0.01 mm sensitivity. The air-dried densities (δ_{12}) of the samples were calculated by the following formula 2:

$$\delta_{12} = \frac{W_{12}}{V_{12}}\ g.cm^{-3} \qquad (2)$$

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

2.2.1. Preparation of test samples

The wood samples with dimension of 25x25x500 mm were cut from the sapwood parts of solid woods and conditioned at a temperature of 20±2°C and 65±5 % relative humidity for three months until they reached an equilibrium in moisture distribution. They were impregnated with boron compounds by vacuum method, with Imersol-Aqua by dipping method and with Timbercare-Aqua by brushing method according to the procedure of the ASTM D 1413-76-99 standards [24] and directions of the manufacturer. Accordingly, the samples of vacuum method were exposed to 760 mm/Hg^{-1} 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 hours 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 hours.

The processes were carried out at 20±2 °C. Retention of impregnation chemical (R) was calculated by the following formula 3:

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

Where, *G* is the amount of impregnation solution absorbed by the sample, T_2 is the sample weight after the impregnation, T_1 sample weight before the impregnation, *C* concentration (%) of the impregnation solution and *V* the volume of the samples. Impregnated test samples were kept under a temperature of 20±2 °C and 65±3 % humidity content until they reach to a stable weight [25].

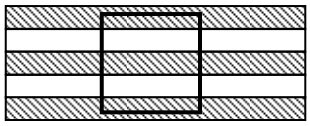
Impregnation test plan is given in Table 1.

Table 1. Impregnation test plan.

Test No	Impregnation Materials	Solution Concentration (%)	Solvent
1	Co	-	-
2	Ba	5.5	Pure water
3	Bx	5.5	Pure water
4	Ba+Bx	5.5	Distilled water
5	Ia	100	-
6	Ta	100	-

Co: Control, Ba: Boric acid, Bx: Borax, Ba+Bx: Boric acid + Borax, Ia: Imersol-aqua, Ta: Timbercare-aqua, N: 12

The laminated veneer lumbers were prepared in the form of five layers from European oak and Lombardy poplar veneers bonded with DVTKA adhesive according to TS EN 386 [26]. 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 approximately 190g.m^{-2}. The spreading rate was calculated by weighting each veneer before and after bonding. Pressure of 0.7 N.mm^{-2} was applied on the bonding line according to the adhesive producers' definition. The solidification time was approximately 30 min. The LVL samples were kept under a temperature of 20±2 °C and 65±5 % relative humidity until reaching to a constant weight. Combustion test samples dimensions of 13x13x76 mm were prepared from the laminated veneer lumbers (Figure 1).



13x13x76 mm

(The thickness of lamellae is 3 mm)

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

2.2.2. Combustion test

Combustion test was determined according to ASTM E 160-50 [27] standards. Relatively, before combustion test, impregnated and laminated samples were conditioned at 27 ^{0}C and 30 % moisture content in a conditioning room until reaching to 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, temperature was set at 315±8 °C in the funnel. Flame source was centered below sample pile and flame source combustion was continued for 3 min. After extinguishing of flame source, without flame source combustion was carried out.

Then the temperature changes of combustion (^{0}C) were determined with digital thermometer. The weights of test samples were measured with an analytic scale of ±0.01g sensitivity.

2.2.3. Statistical analyses

The effect of impregnation with boron compounds, Imersol-aqua and Timbercare-aqua on the combustion properties of LVL produced combination of Oriental Beech, European oak and Lombardy poplar veneers bonded with D_{VTKA} and P_{VAc} adhesives was analyzed by ANOVA (Analysis of Variance). When the differences between groups were found to be significant, Duncan test was used to determine the differences between means at prescribed level of α=0.05.

A total of 24 treatment groups were obtained with 2 different kinds of wood materials, 5 different impregnation chemicals and one control sample. 12 replications were made in each treatment group. Thus, a total of 288 samples (6x4x12) were prepared. Statistical values (ANOVA, Duncan test, mean, deviation of standard, variance, minimum and maximum values) were calculated by the SPSS 13.00.

3. RESULT and DISCUSSION

3.1. Densities and Retention Quantities

The average air-dry densities of LVL wood material which were produced by poplar usage for intermediary layers were determined as 0.542g.cm^{-3} in beech-poplar combination and 0.528g.cm^{-3} in oak and poplar combination.

Results of retention tests were summarized by using descriptive statistics such as the maximum, minimum, mean, standard deviation and variance. Retention of impregnation chemicals are given in Table 2.

ANOVA of the effect of impregnation chemicals on retention of LVL is given in Table 3.

According to ANOVA, the differences between groups were found to be significant ($F_{14:135}$ = 911.638, P<0.05). Duncan test was used to determine the differences between means at prescribed level of α = 0.05 and results of Duncan test are shown in Table 4.

The highest retention quantity was obtained in Oriental beech could be attributable to the effect of permeability. This result may be due to the more penetration of impregnation solution into the wood with the extension of time.

The lowest retention was found in European oak. It was reported that in the impregnation of oak the retention decreased with the increase in impregnation period [28]. This may be due to tyloses in oak wood samples.

Table 2. Retention quantities of impregnation meterials ($kg.m^{-3}$).

Woods	S. Values	Ba	Bx	Ba + Bx	Ia	Ta
Oriental beech	x	16.794	13.598	18.758	198.287	174.302
	Sd	1.0899100	1.2610297	1.2166577	10.029496	8.6344968
	v	1.3198933	1.7668844	1.6447288	111.76755	82.838373
	Min.	15.12	11.35	16.84	188.35	162.75
	Max.	18.92	15.83	20.65	224.26	190.75
European oak	x	3.381	3.853	4.032	63.104	44.196
	Sd	0.3116873	0.3362454	0.4362980	5.725209	3.432247
	v	0.1079433	0.1256233	0.2115066	36.42002	13.08924
	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	6.5550786	6.5150303	10.474254	6.844441	6.959333
	v	47.743395	47.161801	121.90000	52.05153	53.81369
	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 3. The effect of wood types and impregnation materials on retention.

Source	SS	DF	MS	F Value	SIG*
Between Groups	486661.130	14	34761.509	911.638	0.000
Within Groups	5147.660	135	38.131		
Total	491808.790	149			

*P<0.05, Ss: Sum of Squares, DF: Degrees of Freedom, MS: Mean Square, SIG: Significance

Table 4. Retention quantities as a result of Duncan test.

	SUBSET FOR ALPHA = 0.05									
PROCESS	1	2	3	4	5	6	7	8	9	10
O+Ba	3.381									
O+Bx	3.853									
O+(Ba+Bx)	4.032									
B+Bx		13.598								
B+Ba		16.794								
B+(Ba+Bx)		18.758								
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		
B+Ta									174.302	
B+Ia										198.287
Signature	0.826	0.079	1.000	0.088	0.147	0.360	1.000	1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. Uses harmonic mean sample size N: 12, B: Beech, O: Oak, P: Poplar, Ba: Borax, Ba: Boric acid, Ta: Timbercare-aqua, Ia: Imersol-aqua

3.2. The Weight Loss

Results of the weight loss tests were summarized by using descriptive statistics such as the maximum, minimum, mean, standard deviation and variance. The test results of LVL samples are given in Table 5.

Table 5. The weight loss of LVL samples (%).

Type of Process	Type of Adhesive	Statistics Values	C_O	Ba	Bx	Ba + Bx	Ia	Ta
B + P	P_{VAc}	x	0.860	0.836	0.822	0.784	0.864	0.876
		Sd	0.018973	0.016248	0.011661	0.02059	0.013564	0.016248
		v	0.00045	0.00033	0.00017	0.00053	0.00023	0.00033
		Min.	0.83	0.82	0.81	0.75	0.84	0.85
		Max.	0.89	0.86	0.84	0.81	0.88	0.9
	D_{VTKA}	x	0.880	0.886	0.848	0.872	0.888	0.870
		Sd	0.021908	0.040298	0.017204	0.013266	0.027129	0.016733
		v	0.0006	0.00203	0.00037	0.00022	0.00092	0.00035
		Min.	0.85	0.81	0.82	0.85	0.85	0.85
		Max.	0.91	0.92	0.87	0.89	0.93	0.9
O + P	P_{VAc}	x	0.848	0.834	0.826	0.842	0.792	0.868
		Sd	0.016	0.018547	0.018547	0.019390	0.029257	0.018330
		v	0.00032	0.00043	0.00043	0.00047	0.00107	0.00042
		Min.	0.83	0.81	0.8	0.82	0.75	0.85
		Max.	0.87	0.86	0.85	0.87	0.84	0.89
	D_{VTKA}	x	0.866	0.822	0.87	0.852	0.848	0.874
		Sd	0.010198	0.021354	0.026076	0.023151	0.007483	0.025768
		v	0.00013	0.00057	0.00085	0.00067	7E-05	0.00083
		Min.	0.85	0.79	0.84	0.82	0.84	0.84
		Max.	0.88	0.85	0.91	0.89	0.86	0.91

B+P: Beech + Poplar Combination, O+P: Oak + Poplar Combination, 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

Average the weight loss of different impregnation chemical, types of process and adhesive are given in Table 6.

Table 6. Average the weight loss of impregnation chemical, types of process and adhesive.

TYPES OF PROCESS*	Weight loss rate (%)[a]
Beech + Poplar Combination (B+P) : I	0.857 A
Oak + Poplar Combination (O+P) : II	0.845 B
IMPREGNATION CHEMICALS**	**Weight loss rate (%)[a]**
Control (Co)	0.864 AB
Boric acid (Ba)	0.845 BC
Borax (Bx)	0.842 BC
Boric acid + Borax (Ba + Bx)	0.838 C
Imersol-aqua (Ia)	0.848 BC
Timbercare-aqua (Ta)	0.872 A
TYPES OF ADHESIVE***	**Weight loss rate (%)[a]**
Poly(vinyl acetate) (P_{VAc}) : P	0.838 B
Desmodur-VTKA (D_{VTKA}) : D	0.865 A

(a) Different letters in a column refers to significant diferences among types of processes and materials at 0.05 confidence level (*$LSD_{0.5}$: 0.0114, **$LSD_{0.5}$: 0.0198, **$LSD_{0.5}$: 0.0041)

Results of ANOVA, for effect of impregnation chemical, types of process and adhesive on the weight loss rate of LVL samples are given in Table 7.

Table 7. Effect of impregnation chemical, types of process and adhesive on the weight loss during combustion.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Signature (P<0.05)
Factor A	1	0.004	0.004	8.4120	0.0046
Factor B	5	0.018	0.004	6.9054	0.0000
AB	5	0.020	0.004	7.6051	0.0000
Factor C	1	0.022	0.022	41.9400	0.0000
AC	1	0.001	0.001	2.6535	0.1066
BC	5	0.008	0.002	3.0134	0.0143
ABC	5	0.013	0.003	4.8470	0.0005
Error	96	0.051	0.001		
Total	119	0.138			

Factor A = I: B+P (Beech + Poplar combination), II: O+P (Oak + Poplar combination)
Factor B = Co: Control, Ba: Boric acid, Bx: Borax, Ba+Bx: Boric acid + Borax, Ia: Imersol-aqua, Ta: Timbercare-aqua
Factor C = P: (Poly(vinyl acetate)), D: Desmodur-VTKA

The differences between groups were found to be significant (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 8.

Table 8. Duncan test for effect of impregnation chemical, types of process and adhesive on the weight loss rate during combustion.

Impregnation chemical, type of process & adhesive	x	HG*	Impregnation chemical, type of process & adhesive	x	HG*
I+D+(Ba+Bx)	0.888	A	II+D+Ba	0.852	ABCD
I+P+(Ba+Bx)	0.886	A	I+P+Ta	0.850	ABCD
I+P+Ba	0.880	AB	II+P	0.848	ABCD
I+D+Ia	0.876	AB	II+D+(Ba+Bx)	0.848	ABCD
II+D+Ta	0.874	ABC	II+D	0.842	ABCD
I+D+Ba	0.872	ABC	I+P+Bx	0.836	BCDE
II+P+Ta	0.870	ABCD	II+P+Bx	0.834	BCDE
I+D+Ta	0.870	ABCD	II+P+Ia	0.826	CDEF
II+D+Ia	0.868	ABCD	II+P+(Ba+Bx)	0.822	DEF
II+D+Ba	0.866	ABCD	I+P+Ia	0.822	DEF
I+D+Bx	0.864	ABCD	II+D+Bx	0.792	EF
I+P	0.860	ABCD	I+D	0.784	F

*LSD: 0.0396, I: B+P (Beech + Poplar combination), II: O+P (Oak + Poplar combination), P: (Poly(vinyl acetate)), D: Desmodur-VTKA, Co: Control, Ba: Boric acid, Bx: Borax, Ba+Bx: Boric acid + Borax, Ia: Imersol-aqua, Ta: Timbercare-aqua

In the interaction of impregnation chemical, process and adhesive, the weight loss during combustion were found in $B+D_{VTKA}$+Ia (0.888), but the lowest in $B+P_{VAc}$+(Ba+Bx) samples (0.784) (Figure 2).

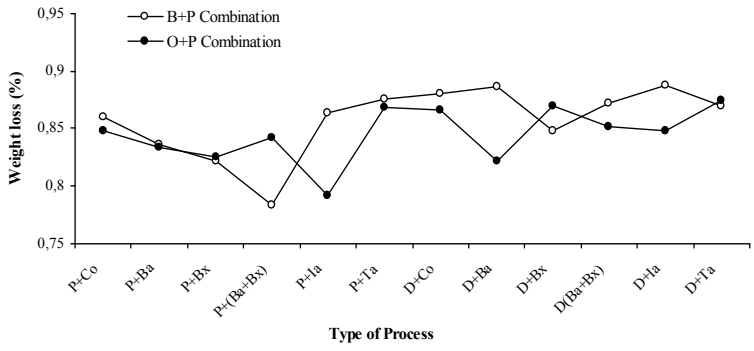


Figure 2. The weight loss rate during combustion changes of impregnated LVL test samples.

4. CONCLUSION

The weight loss of LVL wood material due to combustion was the highest in beech-poplar combination (0.857) and the lowest in oak-poplar combination (0.845). Accordingly, laminated beech-poplar combination has 2 % more weight loss than oak-poplar combination. According to impregnation materials, the weight loss was the highest in Imersol-Aqua (0.872) and the lowest in Ba+Bx (0.838). Impregnated samples showed decreasing effect on the weight loss rate compared to unimpregnated samples except Imersol-Aqua. Thus, weight loss was decreasing in Ba by 2%, Bx by 3%, Ba+Bx by 4%, Ta by 2% and increasing in Ia by 1%.

According the types of adhesive, the weight loss was the highest in D_{VTKA} (0.865) and the lowest in P_{VAc} (0.838). Accordingly, the weight loss of LVL prepared with P_{VAc} was 4% less than materials prepared with D_{VTKA}. This case may be due to resistive property of P_{VAc} against fire.

According to the laminated wood material + impregnation interaction, the weight loss was the highest in beech-poplar combination + Ta (0.876), the lowest in oak-poplar combination + Ta (0.845). Boron compounds decreased, Ta and Ia increased weight loss in beech according to control sample. Thus, it was effected by Ba 1%, Bx 4%, Ba+Bx 5% negatively and Ta 1%, Ia %0.5 positively. In oak-poplar combination, it was effected by Ba 3.5%, Bx 1%, Ba+Bx 1.5 % negatively and Ia 2% positively. Accordingly, impregnation process was effective on the weight loss.

The weight loss of laminated wood material + glue interaction was the highest in beech-poplar combination + D_{VTKA} (0.874), the lowest in oak-poplar combination + P_{VAc} (0.835). The results of P_{VAc} adhesive for the laminated materials might be important in this point of view.

According to the interaction of impregnation materials + adhesives, it was the highest in D_{VTKA} + Ia and P_{VAc} + Ia (0.872), the lowest in P_{VAc} + (Ba+Bx) (0.813). In the laminated material which was prepared with P_{VAc} and D_{VTKA} after impregnation, decreasing effect was observed except P_{VAc} + I. This effect was higher in PVAc.

According to wood material + impregnation material + adhesive type interaction, it was the highest in beech-poplar combination + Ta + D_{VTKA} (0.888) and the lowest in beech-poplar combination + Ta + (Bx+Bx) (0.784). As a result, it can be said that the type of impregnation material has a first degree efficacy and wood material have second degree efficacy on the weight loss. Thus, the weight loss was high in beech-poplar combination impregnated with Ta but low in the same wood material impregnated with Ba+Bx. Besides, the adhesive type should be taken into care. Accordingly, for places which has fire risk, usage of LVL wood material impregnated with boron compounds would be advantageous.

5. REFERENCES

[1] Ching-Mu, T., Wang, Y.L., "Incombustibility of fire retardant coated wood panels", ***Quart. Journal Expt. Forest***, 5: 49-55 (1991).

[2] Le Van, S., Winandy, J.E., "Effect of fire retardant treatments on wood strength", ***Wood and Fiber Science***, 22: 113-131 (1990).

[3] Nussbaum, R., "The effect of low concentration fire retardant impregnations on wood charing rate and char yield", ***Journal of Fire Sciences***, 6: 296-298 (1988).

[4] Ellis, W.D., Rowell, R.M., "Flame retardant treatment of wood with a diisocyanate and an oligomerphosphate", ***Wood and Fiber Science***, 21: 367-370 (1989).

[5] Levan, S.L., Widany, J.E., "Effects of fire retardant treatments on wood Strength", ***Wood and Fiber Science***, 22(1): 118-120 (1990).

[6] Atar, M., Keskin, H., Yavuzcan H.G., "Varnish layer hardness of Oriental beech wood as affected by impregnation and color bleaching", ***Journal of Coatings Technology***, 1: 498-504 (2004).

[7] Harrow, K.M., "Leachability of some water-soluble wood Preservatives", ***Wood Science and Technology***, 32(6): 33-40 (1991).

[8] Sell, J., Feist, W.C., "Weathering behaviour of chromium-copper-boron treated wood", ***Holz als Ron und Werkstoff***, 43: 518-520 (1985).

[9] Baysal, E., "Çeşitli borlu ve WR bileşiklerinin kızılçam odununun bazı fiziksel özelliklerine etkisi", Yüksek Lisans Tezi, ***KTÜ Fen Bilimleri Enstitüsü,*** Trabzon (1994).

[10] Uysal, B., "Combustion properties of LVL bonded with PVA and PF adhesives and impregnated with some chemicals", ***Combustion Science and Technology***, 177(7): 1256-1258 (2005).

[11] Uysal, B., Ozcifci, A., "The effects of impregnation chemicals on combustion properties of laminated wood material", ***Combustion Science and Technology***, 176(1): 117-133 (2004).

[12] Ozcifci, A., "Effects of boron compounds on the bonding strength of PF and MF adhesives to ımpregnated wood materials", ***Journal Adhesion Science Technology***, 20(10):1147-1153 (2006).

[13] Kolmann, F., "Occurrance of exothermic reaction in wood", ***Holz Als Roh-und Werkstoff***, 18: 198-202 (1960).

[14] Goldstein, I.S., "Degradation and protection of wood from thermal attack in wood deterioration and its prevention by preservative treatments", ***Syracuse University***, 1: 307-339 (1973).

[15] Uysal, B., Ozcifci, A., "Ihlamur odunundan PVAc tutkalı ile üretilen lamine ağaç malzemenin yanma özellikleri", ***Gazi University Journal of Science and Technology***, 15: 121-131 (2000).

[16] Yalınkılıc, M.K., Ors, Y., Ay, N., Baysal, E., Demirci, Z., "Duglas göknarı (*Pseudotsuga menziesii* Mirb. (Franco) odununun anatomik ve çeşitli kimyasal maddelerle emprenye edilebilme özellikleri", ***Turkish Journal of Agriculture and Forestry***, 21: 433-444 (1997).

[17] TS 2476, "Odunda fiziksel ve mekaniksel deneyler için numune elde etme metotları ve genel özellikler", ***Türk Standartları Enstitüsü (TSE)***, Ankara (1976).

[18] Ors, Y., Atar, M., Keskin, H., Colakoglu, H.M., "Effects of impregnation with boron compounds on the surface roughness of some woods and varnished surfaces", ***Journal of Applied Polymer Science***, 102(5): 4958-4960 (2006).

[19] Hickson's Timber Impregnation Co. (GB) Ltd. Into the 21st. Century, "Imersol-Aqua and Timbarecare-Aqua Brochure", ***Hickson Timber Treatments Datasheet***, 1-6 (2000).

[20] Ors, Y., Atar, M., Keskin, H., "Bonding strength of some adhesives in wood materials impregnated with Imersol-Aqua", ***International Journal of Adhesion & Adhesives***, 24(4): 292-294 (2003).

[21] POLISAN, "Producer firm text and brochure", Instruction Manuel, Dilovası - Gebze, Kocaeli, Turkey (1999).

[22] TS 2471, "Odunda fiziksel ve mekanik deneyler için rutubet miktarı tayini", ***Türk Standartları Enstitüsü (TSE)***, Ankara (1976).

[23] TS 2472, "Odunda fiziksel ve mekanik deneyler için hacim yoğunluk değerinin tayini", ***Türk Standartları Enstitüsü (TSE)***, Ankara (1976).

[24] ASTM D 1413-76-99, "Standart test method for wood preservatives by laboratory soil-block cultures", ***ASTM Standards***, West Conshohocken, PA (2005).

[25] Keskin, H., Atar, M., Yavuzcan, H.G., "Effect of impregnation and bleaching on the surface hardness of oak wood", ***Journal of Applied Polymer Science***, 93(2): 498-504 (2004).

[26] TS EN 386, "Glued laminated timber-Performance requirements and minimum production requirements", ***Türk Standartları Enstitüsü (TSE)***, Ankara (1999).

[27] ASTM E 160-50, "Standard test method for combustible properties of treated wood by the cribe test", ***ASTM Standards***, West Conshohocken, PA (1975).

[28] Ors, Y., Keskin, H., Atar, M. Colakoglu M.H., "Effects of impregnation with Immersol-aqua on the modulus of elasticity in bending of laminated wood materials", ***Construction and Building Materials***, 21(6): 1649-1650 (2007).