

*Doğuş Üniversitesi Dergisi, 7 (1) 2006, 112-126*

## **COMBUSTION PROPERTIES OF LAMINATED VENEER LUMBERS BONDED WITH PVAC, PF ADHESIVES AND IMPREGNATED WITH SOME CHEMICALS**

### ***BAZI KİMYASALLARLA EMPRENYE EDİLMİŞ VE PF VE PVAc TUTKALI İLE YAPIŞTIRILAN LAMİNE AĞAÇ MALZEMELERİN YANMA ÖZELLİKLERİ***

**Burhanettin UYSAL, Şeref KURT**

*University of Zonguldak Karaelmas, Safranbolu College of Arts and Tech.*

**ABSTRACT:** In this study, we have investigated the effects of impregnation materials  $(\text{NH}_3)_2\text{P}$ ,  $\text{Al}_2(\text{SO}_4)_3$ ,  $\text{K}_2\text{CO}_3$ ,  $\text{CaCl}_2$ ,  $\text{ZnCl}_2$ , on combustion properties of 3 ply laminated veneer lumbers (LVL) produced from fir (*Abies bornmülleriana* Mattf.) by using phenol-formaldehyde (PF), polyvinyl acetate (PVAc). The pressure - vacuum method was used for impregnation process. Combustion test was performed according to the procedure of ASTM-E 69 standards. As a result,  $\text{ZnCl}_2$  was found to be the most successful fire retardant chemical in LVL at PF adhesive. Since it diminishes combustion, the impregnation of LVL produced from fir by using PF adhesive can be advised to be impregnated by using pressure vacuum method.

**Keywords:** Laminated veneer lumbers (LVL), PVAc, Phenol-Formaldehyde, Combustion.

**ÖZET:** Bu çalışmada, polyvinil asetat, (PVAc), fenol formaldehit (PF) tutkalı kullanılarak uludağ göknarından (*Abies bornmülleriana* Mattf.) 3 tabakalı olarak üretilen ve  $(\text{NH}_3)_2\text{P}$ ,  $\text{Al}_2(\text{SO}_4)_3$ ,  $\text{K}_2\text{CO}_3$ ,  $\text{CaCl}_2$ ,  $\text{ZnCl}_2$  ile emprenye edilmiş malzemelerin yanma özellikleri araştırılmıştır. Emprenye işlemi basınç- vakum yöntemi kullanılarak uygulanmıştır. Yanma testleri ASTM-E 69 standartlarına göre yapılmıştır. Sonuç olarak yanmaya karşı en başarılı, çinko klorür ile emprenye edilmiş PF tutkallı LVL bulunmuştur. Yanma olayını geciktirdiği için, PF tutkalı kullanılarak Uludağ göknarından üretilen ve basınç - vakum metodu ile emprenye edilen LVL önerilebilir.

**Anahtar Kelimeler :** Lamine ağaç malzeme, PVAc, fenol formaldehit, yanma

### **1. Introduction**

It is not sufficient merely to study the emissions from a stove without looking in some detail at the processes, which are taking place within the stove. The combustion of wood relates to the fuel burn rate (or the reaction rate), the combustion product (or the emissions), the required excess air for complete combustion, and the fire temperatures. The processes are extremely complicated, principally, because the wood has a complex physical and chemical composition. The burning of hydrocarbon is frequently chaotic. "Above a certain temperature objects can suddenly burn into flame, burn furiously, then when the heat produced drops off, the flame can suddenly cease. The reaction can choose between two stable modes chaos" (Scott, S., 1992).

Laminated material (LAM) produced from massive wood material is used as a furniture material and is an important building material in wood working industry. It is possible to produce desired form and shape of LAM with lamination technique. According to the wood material, LAM has some technical and economical advantages.

TS 11878 (1995) describe laminated wood as follows; laminated wood is obtained from wood sheets produced by sliced, sawing and rotary methods. Between the sheets different adhesives are applied and pressed as smooth and moulding shapes by cold and hot pressing method.

The demand for engineered wood products (such as oriented strand board, glulam and laminated veneer lumber - LVL) has increased due to a constant increase in the global population. The grain of each layer of veneer assembled into LVL runs parallel with each adjacent ply (Badwin, R.F.). Being a homogeneous and dimensionally stable building material, LVL can be used where strength and stability are required (Colak, S., et al. 2004).

Long-term retardants consist of same inhibiting chemicals dissolved in water. They remain effective even after water has been removed by evaporation. The key ingredient in these retardants is the active retardant salt, usually referred as ‘‘active salt’’, which is typically either an ammonium sulfate or ammonium phosphate. All salts are not equally effective, when applied to fuels in the same concentration. By adjusting the amount of salt, applied to the fuel, we may achieve the maximum performance (George CW, Johnson CW 1986).

Recently study have impregnated scotch pine and beach wood by using dipping method with potassium nitrate ( $\text{KNO}_3$ ), zinc sulphate ( $\text{ZnSO}_4$ ), Sodium tetra borate ( $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10 \text{H}_2\text{O}$ ), sodium sulphate ( $\text{Na}_2 \text{SO}_4$ ) and copper sulphate ( $\text{Cu}_2 \text{SO}_4$ ).  $\text{Cu}_2 \text{SO}_4$ ,  $\text{ZnSO}_4$  and  $\text{Na}_2 \text{SO}_4$ . They found these chemicals to be effective against combustion. They do not, however, give any details of the different emissions characteristics of the fuels (Örs, Y., et al.1999).

At the same time Uysal et al (2000) have obtained laminated wood produced from Uludağ fir for out ply, and different veneer materials for core ply were used and bonded with PVAc. The combustion test was applied to the test samples. The highest mass reduction and concentration of  $\text{O}_2$  were observed in white mulberry and the highest heat increase in Scotch pine used in core ply .

The investigation of Kolmann (1960) yielded pertinent information the thermal degradation of the hardwood species is lower than sapwood species, for hardwood contains more sensitive pentozans.

Goldstein (1973) evaluated the lignin of spruce started degradation between 130-145°C and its cellulose between 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 %.

In the study Uysal et al. (2000) carried out 3 layered LAM, produced from PVAc adhesive and lime-tree and consisting of different core ply was tested according to the procedure of ASTM-E 69 combustion standards. The highest amount of ash and

unburned pieces were obtained in LAM consisting of lime-tree. Yalınkılıç et al. (1996) has studied impregnation of the Douglas (*Pseudotsuga menziesii* (mirb) franco) with boron compounds and the groups of the PEG-400, and the test samples were applied to the combustion test. Although the groups of the PEG-400 had negative effects on combustion, boron compounds were more effectual.

Uysal et al. (2004) investigated the combustion properties of LVL from Uludağ fir wood samples impregnated with some chemicals by using dipping process. They found the highest mass reduction in massive samples impregnated with Tanalith-CBC, CO and CO<sub>2</sub> ratio in massive control samples, which were unprocessed. On the other hand the highest temperature variation in laminated samples impregnated with Tanalith-CBC, O<sub>2</sub> ratio in massive wood samples impregnated with sodium tetra borate and ash ratio in laminated samples impregnated with sodium perborate were obtained.

The aim of this paper is to investigate the combustion properties and emission testing of LVL manufactured from fir, widely used in building and construction. The LVL samples were impregnated with (NH<sub>3</sub>)<sub>2</sub>P, Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>, K<sub>2</sub>CO<sub>3</sub>, CaCl, ZnCl<sub>2</sub>, by means of pressure – vacuum method.

## 2. Material and Method

### 2.1. Wood Material

*Abies bornmülleriana* Mattf. (Uludag fir) was used in LVL production. The test samples were chosen randomly from timber merchants of Ankara, Turkey. Special emphasis is given for the selection of the wood material. Accordingly, non-deficient, proper, knotless, normally grown (without zone line, without reaction wood and without decay, insect mushroom damages) wood materials are selected.

### 2.3. Adhesive

The following adhesives were used in this experiment: PVAc is an odorless, non-flammable adhesive. It can be used in cold temperatures and solidifies quickly. The application of this adhesive is very easy and it does not damage the tools during the cutting process. However, mechanical resistance of PVAc adhesive decreases by increasing heat. It loses bonding resistance capacity over 70 °C. Using 150–200 g/m<sup>2</sup> the adhesive seems to be suitable on condition that it is applied to only one surface (Ors Y 1987).

TS 3891(1983) standard procedure was used for applying PVAc adhesive. The density of PVAc should be 1.1 g/cm<sup>3</sup>, the viscosity 16.000±3.000 mPa s, and pH value and ash ratio should be 5 % and 3 %, respectively. A pressing time of 20 min for the cold process and 2 min and 80 °C are recommended with 6–15 % humidity for the jointing process. After a hot-pressing process, the materials should be attended until its normal temperature is reached. PVAc adhesive was supplied from POLISAN, a producer firm in İzmit, Turkey.

The building blocks for PF are phenol and formaldehyde. Phenol is derived from crude oil. Phenol's principal feedstock is toluene and benzene. Toluene is converted into benzoic acid; benzene is combined with propylene into cumene. Together with benzoic acid it forms phenol.

Phenol and formaldehyde are combined in a reactor into PF resin. It is commonly shipped to engineered wood products plants as a colloidal aqueous solution with a solid content between 30 % (for LVL) and 50 % Oriented Strand Board. This liquid is odorless, of dark-brownish colour, and, of course, not flammable. When shipped, the PF liquid, just like the UF, is polymerized and cross-linked to a certain degree. In the PF solution, phenol and formaldehyde are available at a molar ratio of about 2.2. Most of the formaldehyde will be bonded permanently within the three-dimensional cross-linked PF network (Colakoğlu, G., 1998).

#### 2.4. Impregnation Chemicals

As impregnation chemicals;  $(\text{NH}_3)_2\text{P}$ ,  $\text{Al}_2(\text{SO}_4)_3$ ,  $\text{K}_2\text{CO}_3$ ,  $\text{CaCl}$ ,  $\text{ZnCl}_2$ , were used .

#### 2.5. Impregnation Process

In impregnation process pressure - vacuum method has been applied.

Before and after impregnation, after test samples being kiln dried, the amount of retention ( $R$ ,  $\text{kg}/\text{m}^3$ ) and ratio of retention ( $R$ , %) were calculated as follows;

$$R = \frac{G \times C}{V} 10^6 \quad R(\%) = \frac{M_{di} - M_d}{M_d} 100 \quad (1,2)$$

Here;

$G = T_2 - T_1$   $T_2 =$  sample mass after impregnation [kg]

$T_1 =$  sample mass before impregnation [kg]

$M_{di} =$  full dried mass after impregnation [kg]

$M_d =$  full dried mass before impregnation [kg]

$V =$  volume of sample [ $\text{cm}^3$ ]

$C =$  concentration of solution [%]

Impregnation test plan is given in Table 1.

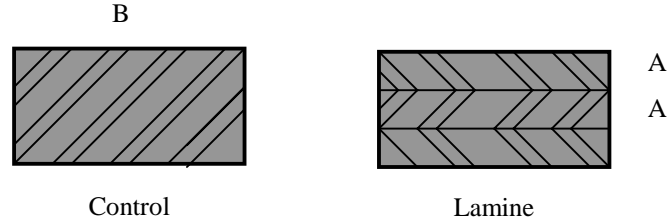
**Table 1. Impregnation Test Plan**

Test No	Impregnation chemicals	Sample humidity (%)	Solution concentration (%)	Solvent
1	Control	12	-	-
2	Natural	12	-	-
3	$(\text{NH}_3)_2\text{P}$	12	10	Pw
4	$\text{Al}_2(\text{SO}_4)_3$	12	10	Pw
5	$\text{K}_2\text{CO}_3$	12	10	Pw
6	$\text{CaCl}$	12	10	Pw
7	$\text{ZnCl}_2$	12	10	Pw

Pw: Pure water

#### 2.6. Preparation of Test Samples

The oversized test samples were climatized until they were stable at  $20 \pm 2$  °C and  $65 \pm 3$  % relative humidity in climate room. Later on they were cut with the dimensions of  $3 \times 22 \times 1030$   $\text{mm}^3$  and bonded with phenol-formaldehyde (PF) and poly (vinyl acetate) (PVAc) as 3 layered LVLs ( $9 \times 19 \times 1016$  mm) according to the procedure of ASTM E – 69 (1975). 10 samples were manufactured for each test sample (lamina control, massive wood and lamina) 130 test samples were prepared in total (Figure 1).



**Figure 1. Lamine Test Samples (A = 3 mm, B = 19 mm)**

### 2.7. Execution of the Test

The combustion test was carried out according to the principles of the ASTM E 69. But some changes were made in the stand. For this purpose, a digital balance having 0.01 g sensitiveness has been used for determination of mass reduction of materials when they are burnt. Butane gas was used to make an ignition flame. The gas flow is standard as the height of the flame is 25 cm, the temperature must be 1000 °C. The distance between the bottoms of the test samples, which were hung inside of the fire tube and the top of the gas pipe must be adjusted as 2.54 cm. During the test, mass reduction, temperature and released gas Carbon monoxide (CO), Nitrogen oxide (NOX), Sulfur dioxide (SO<sub>2</sub>), Oxygen (O<sub>2</sub>) were determined in every 30 seconds. The test was made under a chimney where the flow of air blown was drawn with natural draft. At the beginning of combustion, test flame source was used for 4 minutes then flame source was taken away and it continued for 6 minutes. The total time for the test was 10 minutes.

Testo 300 M and XL flue gas analyser was used for measuring concentration of the released gasses (CO, NOX, SO<sub>2</sub>, O<sub>2</sub>), and temperature variation. The probe was inserted into the first hole from the top of the fire tube. Technical data of Testo 300 M and XL flue gas analyser is as follows.

#### Temperature measurement

Measuring range	-40 to +1200 °C
Accuracy	± 0.5 °C (0 to +99.9 °C) ± 0.5 % of m.v.(from +100 °C)
Resolution	0.1/1 °C (from +1000 °C)
Sensor	Thermocouple, Type K (NiCr-Ni)

#### CO measurement

Measuring range	0 to 8000 ppm
Accuracy	±20 ppm (to 400 ppm) ±5 % of m.v. (to 2000 ppm) ± 10 % of m.v. ( to 8000 ppm)
Measuring procedure	Electrochemical measuring cell
Response time t 90	< 30 s

#### NOX measurement

Measuring range	0 to NOX max
Accuracy	± 0.2 vol. % absolute
Resolution	0.1 vol. %
Measuring procedure	Electrochemical measuring cell
Response time t 90	< 30 s

**SO<sub>2</sub> measurement**

Display range	0 to SO <sub>2</sub> max
Accuracy	± 0.2 vol. %
Resolution	0.01 vol . %
Measurement	Electrochemical measuring cell
Response time t 90	< 30 s

**O<sub>2</sub> measurement**

Measuring range	0 to 21 vol.%
Accuracy	± 0.2 vol. % absolute
Resolution	0.1 vol . %
Measuring procedure	Electrochemical measuring cell
Response time t 90	< 20 s

**2.8. Statistical Procedure**

To determine both the amount of retention in the prepared natural and lamine samples and the effects of impregnation material on combustion with or without flame source, multivariate analysis was applied. Based on Duncan's test significant each test group was compared with one another and itself.

**3. Result and Discussion****3.1. Peculiarities of the Solution**

Properties of the solution used in impregnation process are given in Table 2.

As a result of using fresh solution in every impregnation process, there is no important change in the acidity and density of the solutions before and after the impregnation, the pH value of aluminium sulphate solution in acidic zone is 3,5 and this may be effectual on polysaccharide of the wood.

**Table 2. Peculiarities of Impregnation Chemicals**

Impregnation Chemicals	Solvent	Temperature (°C)	pH		Density (g/ml)	
			BI	AI	BI	AI
(NH <sub>3</sub> ) <sub>2</sub> P	Pure water	23	8	8	1.090	1.140
Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	Pure water	23	3.50	3.50	1.080	1.080
K <sub>2</sub> CO <sub>3</sub>	Pure water	23	12	12	1.190	1.190
CaCl	Pure water	23	7	7	1.120	1.130
ZnCl <sub>2</sub>	Pure water	23	6	5.5	1.120	1.130

BI: Before impregnation    AI: After impregnation

**3.2. Retention**

The proportion of impregnation chemicals is given in Table 3.

The highest retention proportion was observed in zinc chloride and the lowest in diammonium phosphate.

**Table 3. Proportion of Retention**

Test no	Impregnation chemicals	Retention (%)	
		$\bar{X}$	HG *
1	K <sub>2</sub> CO <sub>3</sub>	12,32	A
2	CaCl	11,52	B
3	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	16,97	C
4	ZnCl <sub>2</sub>	20,14	D
5	(NH <sub>3</sub> ) <sub>2</sub> P	9,38	E

$\bar{X}$  : Average \*HG: Groups of Homogeneity

### 3.3. Air Dry Density

The average densities of LVL samples, containing 12 % humidity are given in Table 4.

**Table 4. Air Dry Density of Wood Samples (g/cm<sup>3</sup>)**

Samples	$\delta_{12}$ (WithPVAc)	$\delta_{12}$ ( With PF)
I- Control		0,43
II- Lamina Control	0,45	0,47
III- Lamina (NH <sub>3</sub> ) <sub>2</sub> P	0,49	0,51
IV- Lamina Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	0,53	0,55
V- Lamina K <sub>2</sub> CO <sub>3</sub>	0,51	0,53
VI- Lamina CaCl	0,50	0,52
VII- Lamina ZnCl <sub>2</sub>	0,54	0,56

The highest density was observed in laminated wood samples impregnated with zinc chloride. According to the control samples, it is possible to say that impregnation chemicals and glue increased the density of LVL.

### 3.4. Values of Combustion Attributes

Obtained average values based on impregnation chemicals are given in Table 5.

The multivariate analyse applied on the data obtained from the combustion test is given in Table 6.

**Table 5. Average Combustion Values of Impregnation Chemicals**

	Cont	PVAc Lamine						PF Lamine					
		Impreg. chemicals	Wood cont	LVL cont	(NH <sub>3</sub> ) <sub>2</sub> P	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	K <sub>2</sub> CO <sub>3</sub>	CaCl	ZnCl <sub>2</sub>	LVL cont	(NH <sub>3</sub> ) <sub>2</sub> P	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	K <sub>2</sub> CO <sub>3</sub>
CO	726	1008	384	412	812	93	332	983	19	414	352	360	246
NOX	9,95	13,3	18,6	10,1	16,5	2,1	14,0	25,1	2,8	10,6	8,9	8,9	7,7
SO <sub>2</sub>	1,52	2,77	1,52	1,01	1,37	0,57	1,80	0,57	0,42	1,40	0,17	1,80	2,12
Temp.	333	266	155	201	203	181	160	277	163	153	206	181	196
O <sub>2</sub>	18,3	17,8	19,5	19,1	17,8	19,8	19,7	17,6	20,3	19,1	20,3	19,6	19,8
Mass reduct. (Value)	21,0	12,1	6,2	23,7	18,1	17,0	5,1	6,1	2,6	16,9	20,8	9,0	6,3

**Table 6. The Multivariate Analyze Connected with adhesive type, impregnation type, find of value and measurement of time**

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1671053966,689	1559	1071875,540	412,938	,000
Intercept	231717267,422	1	231717267,422	89268,596	,000
A	6314945,975	2	3157472,988	1216,410	,000
B	18289378,012	5	3657875,602	1409,189	,000
C	568267307,982	5	113653461,596	43784,760	,000
D	62732745,647	19	3301723,455	1271,982	,000
A * B	12036506,986	5	2407301,397	927,408	,000
A * C	27390995,072	10	2739099,507	1055,232	,000
B * C	75667619,608	25	3026704,784	1166,032	,000
A * B * C	60133730,156	25	2405349,206	926,656	,000
A * D	11068584,732	38	291278,546	112,214	,000
B * D	24454780,427	95	257418,741	99,170	,000
A * B * D	29162520,922	95	306973,904	118,261	,000
C * D	187049219,891	95	1968939,157	758,530	,000
A * C * D	51190656,995	190	269424,511	103,795	,000
B * C * D	125700487,733	475	264632,606	101,949	,000
A * B * C * D	129982151,092	475	273646,634	105,422	,000
Error	12148021,378	4680	2595,731		
Total	2008518874,612	6240			
Corrected Total	1683201988,066	6239			

Factor A = Adhesive type (PVAc and PF)

Factor B = Impregnation type ( (NH<sub>3</sub>)<sub>2</sub>P, Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>, K<sub>2</sub>CO<sub>3</sub>, CaCl, ZnCl<sub>2</sub>, Control )

Factor C = Find of value ( CO, NOx, SO<sub>2</sub>, temperature, O<sub>2</sub> )

Factor D = Measurement of time (30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 360, 390, 420, 450, 480, 510, 540, 570, 600 second)

According to the variance analysis, the effects of adhesive type, impregnation type and measurement of time on mass reduction, temperature and released gas (CO, NOX, SO<sub>2</sub>, O<sub>2</sub>) were statistically significant. The interaction between factors was statistically identical (p < 0.05).

The mean values of the variation sources that were found to be significant were compared using Duncan's test and the results are summarized in Table 7 and 8.

**Table 7. Duncan Test Results of LVL (p ≤ 0.05)\*.**

Source of Variance	CO (ppm)	NOX (ppm)	SO <sub>2</sub> (ppm)	Temp. (°C)	O <sub>2</sub> (%)	Mass reduct. (%)
PF-(NH <sub>3</sub> ) <sub>2</sub> P	19,40a	2,82ab	,425a	163,20a	20,31c	2,6a
PVAc- Cacl	93,30ab	2,05a	,575ab	181,21a	19,83bc	17,0cd
PF- ZnCl <sub>2</sub>	246,05bc	7,72bc	2,125de	196,16a	19,80bc	6,3ab
PVAc- ZnCl <sub>2</sub>	332,57c	14,02ef	1,800cd	160,32a	19,68bc	5,1ab
PF- K <sub>2</sub> CO <sub>3</sub>	352,67c	8,90cd	,175a	206,82a	20,27c	20,8cde
PF- CaCl	360,15c	8,97cd	1,800cd	181,37a	19,56bc	9,0bc
PVAc-(NH <sub>3</sub> ) <sub>2</sub> P	384,50c	18,60f	1,525bcd	155,44a	19,50bc	6,2ab
PVAc- Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	412,25c	10,12cd	1,012abc	201,96a	19,14b	23,7e
PF- Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	414,22c	10,62cd	1,400bcd	153,78a	19,11b	16,9c
Massive Control	726,10d	9,95cd	1,525bcd	333,29c	18,28a	21,0de
PVAc- K <sub>2</sub> CO <sub>3</sub>	812,37d	16,52f	1,375bcd	203,00a	17,82a	18,1cd
PF-Control	983,87e	25,12g	,575ab	277,15b	17,63a	6,1ab
PVAc-Control	1008,90e	13,32cde	2,775e	266,23b	17,82a	12,1c



\* The mean values marked with the same symbol are statistically identical

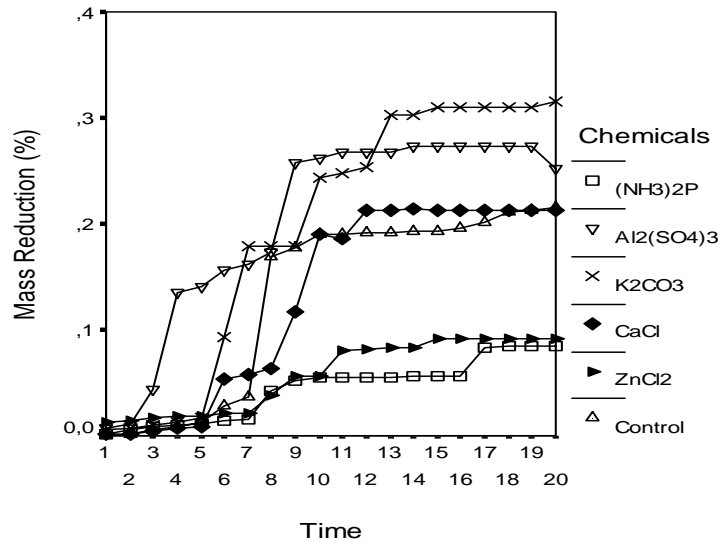
**Table 8. Duncan Test Results of LVL with measurement of time ( $p \leq 0.05$ )\*.**

Measurement of time	CO (ppm)	NOx (ppm)	SO <sub>2</sub> (ppm)	Temp. (°C)	O <sub>2</sub> (%)	Mass reduct. (%)
	x	x	x	x	x	x
19,00	99,03a	2,07a	0,307a	72,63a	20,88j	23,01e
18,00	133,53ab	2,26ab	0,307a	76,78a	20,87j	22,98e
20,00	146,88ab	5,11ab	0,884ab	71,73a	20,43ghı	23,02e
17,00	151,76abc	2,38ab	0,384a	80,75a	20,85j	22,97e
16,00	175,80abc	2,26ab	0,384a	81,13a	20,83ij	22,56e
15,00	198,88abcd	2,61ab	0,384a	90,28ab	20,81ij	22,56e
14,00	239,92de	2,61ab	0,230a	94,12abc	20,76hij	22,21e
13,00	281,88de	2,50ab	0,115a	100,88abc	20,74ghij	22,03de
1,00	310,57def	18,73d	2,269cd	229,98f	17,28d	0,41a
12,00	345,42efg	3,03ab	0,442a	118,45bcd	20,62ghij	21,25de
2,00	432,84fgh	24,69e	2,461d	274,95g	16,30b	0,65a
11,00	443,38gh	3,92ab	0,461a	123,28cd	20,47ghij	20,57de
10,00	545,30hı	4,73ab	0,653a	132,34d	20,38gh	20,04de
3,00	579,50ı	32,53f	2,615d	385,83h	15,89a	1,00a
4,00	728,50j	30,73f	2,673d	447,94ı	15,78a	1,63a
9,00	737,73j	5,23b	0,711a	170,54e	20,35g	17,65cd
8,00	900,46k	10,53c	1,615bc	294,11g	19,30f	14,89c
5,00	964,92kl	31,07f	4,115e	462,67ı	15,76a	2,02a
6,00	987,69kl	25,23e	2,961d	445,46ı	16,82c	4,46a
7,00	1087,07l	18,42d	2,615d	364,97h	17,88e	9,02b

The mean values marked with the same symbol are statistically identical.

The highest mass reduction was obtained from the PVAc adhesive LVL, impregnated with aluminium sulphate, the lowest value from the PF adhesive LVL, impregnated with di-ammonium phosphate.

The results connected with these values are shown in Figure 2.



**Figure 2. The Mass reduction (%)**

As a result of combustion, the highest reduction of  $O_2$  concentration was measured in PF adhesive LVL control and the lowest change of  $O_2$ -concentration in combustion of PF adhesive LVL impregnation processed with di-ammonium phosphate. Inorganic materials act as heat sink, lowering combustion efficiency. Also, inorganic materials favour the formation of char. The results connected with these values are shown in Figure 3.

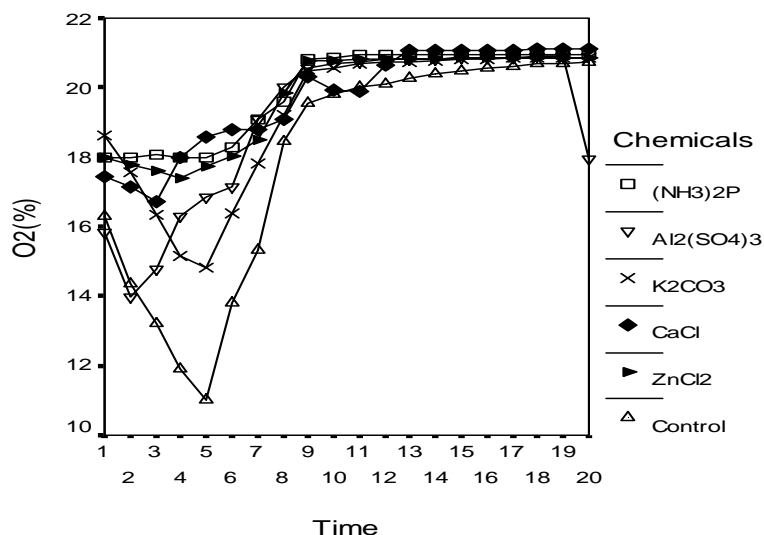
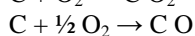
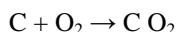


Figure 3.  $O_2$  -ratio in the combustion gases (%)

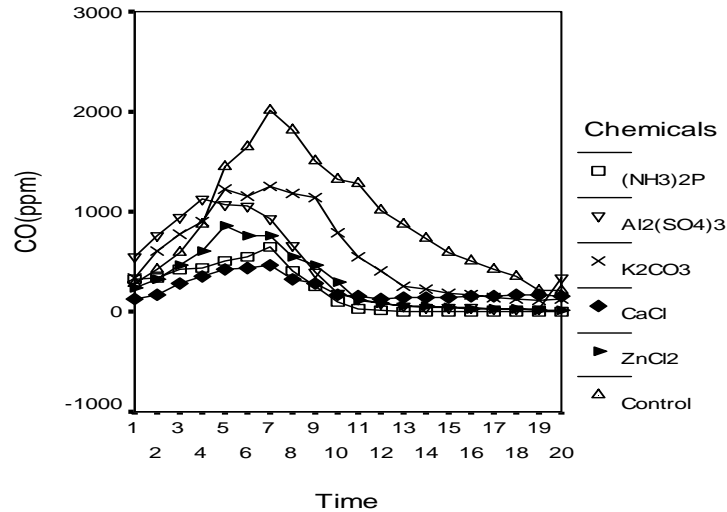
The concentration of oxygen remained almost constant after the start of the combustion with all the other samples except control sample. 21 % is the proportion of oxygen in air normally. So the treated samples have reacted very slowly with oxygen and burned poorly. Impregnation chemicals had fire retardant effects according to the control samples.

Carbon can oxidise to form either carbon monoxide or carbon dioxide according to the following equations:



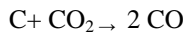
At lower temperatures and in the presence of sufficient oxygen the formation of  $CO_2$  dominates. At higher temperature  $CO$  is formed preferentially, and either escapes or burns later, well away from the solid carbon. The ratio of  $CO$  to  $CO_2$  is influenced by various anions and cations.

The highest increase in  $CO$  concentration was observed in the experiment of PVAc adhesive LVL control samples and the lowest in those of PF adhesive LVL samples impregnation processed with di-ammonium phosphate. The results connected with these values are shown in Figure 4.

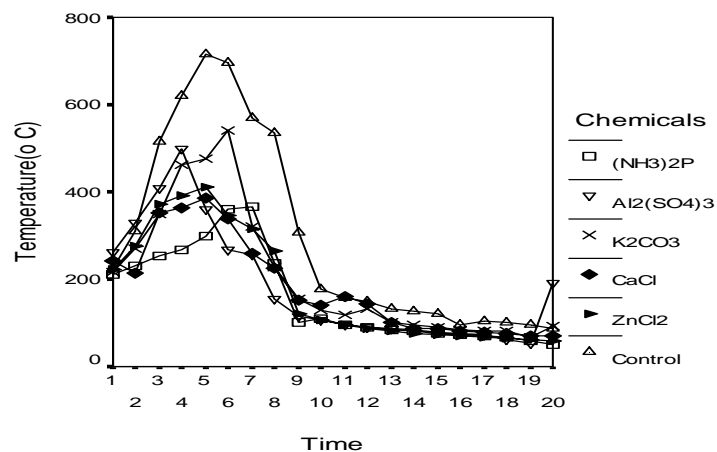


**Figure 4. Variation of CO Ratio (ppm)**

There is no important change in CO proportion in test samples due to flame source in the first stage of combustion. As a result of moving the flame source from fire tube (3-4 minutes, after the beginning of combustion), a linear motion was observed in impregnated samples at the stage of in flame source combustion. As for control samples, there was important change in CO ratio because of combustion's going on at the stage of in flame source combustion. Based on the control samples, impregnation chemicals decreased the occurrence of CO by diminishing the combustion. At very high temperature no oxygen reaches the carbon and it therefore burns in  $\text{CO}_2$  according to the following reaction equation:



The highest temperature variation was observed in massive control samples and the lowest in PF adhesive LVL impregnation processed with aluminium sulphate. The results connected with these values are shown in Figure 5.



**Figure 5. Temperature Variation during the experiments (°C)**

If flames are present, fire temperatures are high and more oxygen is available from thermally induced convection. The lower temperatures of the smouldering stage results in a lower oxygen supply from diffusion into the fuel bed; gasses in this phase which leave the fuel bed are not oxidised further (Lobert, J., et al. 1991).

At the first stage of the combustion, there occurred an increase in temperature due to the flame source, and a decrease as a result of the flame source's getting far away from fire tube.

The highest concentrations of  $\text{SO}_2$  were observed in PVAc adhesive LVL control samples and the lowest in PF adhesive LVL samples impregnation processed with potassium carbonate and di-ammonium phosphate. The results connected with these values are shown in Figure 6.

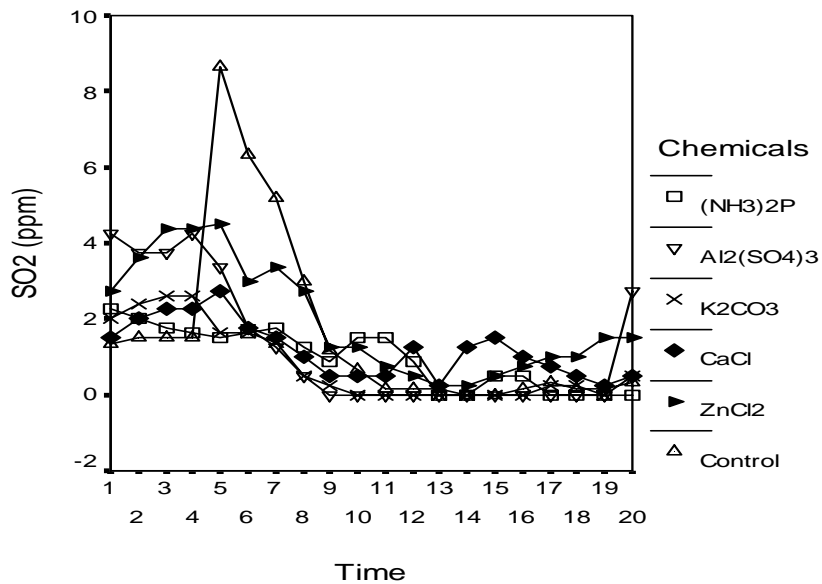


Figure 6. Variation of the  $\text{SO}_2$  (ppm)

In this study, the highest increase in NOX concentration was observed in the experiment of PF adhesive LVL control samples and the lowest in those of PVAc adhesive LVL samples impregnation processed with calcium chloride and PF adhesive LVL samples impregnation processed with di-ammonium phosphate. The results connected with these values are shown in Figure 7.

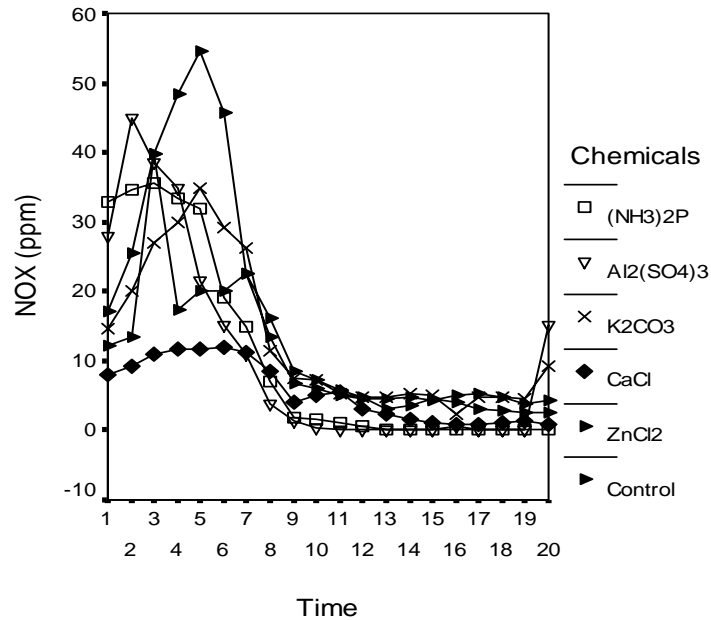


Figure 7. Variation of the NOX (ppm)

According to the control samples it can be said that impregnation chemicals show the effect of fire retardant. Control samples gave the highest CO<sub>2</sub> concentrations.

#### 4. Conclusion

In the first 4 minutes, the first stage of the experiment, combustion in all the samples occurred nearly at the same time. The highest mass reduction (23.70 %) was observed in PVAc adhesive LVL samples impregnation processed with aluminium sulphate, the second stage of combustion after the movement of flame source from fire tube.

Insoluble compounds act as a heat sink lowering combustion efficiency, but soluble ionic compound can have a catalytic effect on the pyrolysis and combustion of the wood (Shafizadeh, F., 1981.).

At the end of combustion test, the most average O<sub>2</sub> consumption ratio was seen in PF adhesive LVL control samples with the value of 17.63 % (O<sub>2</sub>). The lowest average O<sub>2</sub> consumption ratio was observed in PF adhesive LVL impregnation processed with di-ammonium phosphate with the ratio of 20,31 % O<sub>2</sub>.

The highest CO ratio was observed in PVAc adhesive LVL control samples (1008.9 ppm); the lowest in PF adhesive LVL samples treated with di-ammonium phosphate (19.40 ppm). As well known, there are two forms of reaction between C<sub>2</sub> and O<sub>2</sub> during combustion. Combustion ratio of a sample is directly connected to the sum of the amount of CO and CO<sub>2</sub> emissions. Because the combustion tests are made in an open environment, there is not a lack of O<sub>2</sub> and poor mixing. Ways of both samples with O<sub>2</sub> are identical. Thus, both the amounts of CO and CO<sub>2</sub> emissions of the tests made with PVAc adhesive LVL samples, treated by zinc chloride, are lower than

LVL and wood control samples. It is possible to say that impregnation chemicals have fire retardant effect.

Due to fire resource, at the first stage of the combustion test, linear increase was observed in temperature variation. The temperature decreased when the fire source got away from the fire tube, PF and PVAc adhesive LVL samples impregnation processed, wood control samples. This situation, impregnation effect decrease or end of burning phenomenon after the fire source got away from the fire tube.

As a produce the burning were occurred emission, which are the highest concentrations of SO<sub>2</sub> were observed in PVAc adhesive LVL control samples (2,77 ppm) and the lowest in PF adhesive LVL samples impregnated with potassium carbonate (0,17 ppm).

The highest increase in NOX concentration was observed in the experiment of PF adhesive LVL control samples (25,12 ppm) and the lowest in those of PVAc adhesive LVL samples impregnation processed with calcium chloride (2,05 ppm) and of PF adhesive LVL samples impregnated with di-ammonium phosphate (2,82ppm).

Di-ammonium phosphate ranked first in reducing flame spread, followed by monoammonium phosphate, ammonium chloride, ammonium sulphate, borax and zinc chloride. Zinc chloride, although excellent as a flame retardant, promoted smoke and glowing (Levan, L. S., 1984).

As a result; di-ammonium phosphate was found to be the most successful fire retardant chemical in LVL at PF adhesive. Since it diminishes combustion, the impregnation of LVL produced from fir by using PF adhesive can be advised to be impregnated by using pressure vacuum method.

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