

**COMBUSTION PROPERTIES OF MULBERRY
(*MORUS ALBA* L.) LAMINATED VENEER LUMBERS
BONDED WITH PVAC, PF ADHESIVES AND
IMPREGNATED WITH SOME FIRE-RETARDANTS**

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ABSTRACT

In this study, the effects of impregnation materials di-ammonium phosphate, aluminium sulphate, potassium carbonate, calcium chlorur, zinc chlorur on combustion properties of 3 ply laminated veneer lumbers (LVL) produced from mulberry (*Morus alba* L.) by using of phenol-formaldehyde (PF), poly (vinyl acetate) (PVAc) have been investigated. The pressure-vacuum method was used for impregnation process. Combustion test was performed according to the procedure of ASTM-E 69 standards. According to the test results zinc chloride was found to be the most successful fire retardant chemical in LVL with PF adhesive. Since zinc chloride diminishes combustion, LVL produced from mulberry with PF adhesive and impregnated with zinc chloride can be advised to be used as a fire resistant building material where required.

KEY WORDS: laminated veneer lumbers (LVL), PVAc, phenol-formaldehyde, fire retardant

INTRODUCTION

It is not sufficient merely to study the emissions from a stove without looking in some details at the processes 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 flames, burn furiously, then when the heat source is taken, the flame can suddenly cease. (Scott, 1992).

Fire-reterdant treatments for wood can be classified into two general classes; those impregnated into the wood or incorporated into wood composite products, and those applied as paint or surface coatings (Baker, D.S. Chemical Ind. (London) 1977, 74-79)

Laminated material (LAM) produced from massive wood 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. When compared with wood material, LAM has some more technical and economical advantages.

TS 11878 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 moulded by cold and hot pressing method.

The demand for engineered wood products (such as oriented strand board, LVL) has increased due to a constant increase in the global population. The grain of each layer of veneer lumbers assembled into LVL runs parallel with each adjacent ply (Badwin, 1990). Being a homogeneous and dimensionally stable building material, LVL can be used where strength and stability is required (Colak et al. 2004).

In recent studies Scotch pine and beach wood have been impregnated by using dipping method with potassium nitrate (KNO_3), zinc sulphate (ZnSO_4), Sodium tetra borate ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$), sodium sulphate (Na_2SO_4) and copper sulphate (Cu_2SO_4). Cu_2SO_4 , ZnSO_4 and Na_2SO_4 , these chemicals were found to be effective against combustion. However, no details of the different emission characteristics of the fuels were given (Örs et al. 1999).

At the same time Uysal and Özçifçi (2000a) have obtained the laminated wood produced from Uludağ fir for out ply, and different veneer materials bonded with PVAc were used for core ply. The combustion test was applied to the test samples. The highest mass reduction and concentration of O_2 was observed in white mulberry and the highest heat increase was observed in Scotch pine used as core ply (Uysal and Özçifçi 2000b).

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

Goldstein (1973) evaluated the lignin of spruce starting 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 % (Goldstein 1973).

In this study Uysal and Özçifçi (2000) carried out 3 layered LAM, produced from PVAc adhesive and lime-tree and consisting of different core plies and it was tested according to the procedure of ASTM-E 69 combustion standards. The highest amount of ash and unburned pieces were obtained in the LAM produced from lime-tree (Uysal and Özçifçi 2000).

Yalınkılıç and Örs (1996) have studied impregnation of Douglas (*Pseudotsuga menziesii* (MIRB) FRANCO) with boron compounds and the groups of PEG-400, and the test samples were applied to the combustion test. Although the groups of PEG-400 had negative effects on combustion, boron compounds were found more effectual. (Yalınkılıç and Örs 1996).

Uysal and Özçifçi (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 the massive samples impregnated with Tanalith-CBC, and the highest ratio of CO and CO_2 was found in the unprocessed massive control samples. On the other hand the highest temperature variation was obtained in laminated samples impregnated with Tanalith-CBC, the most consumed ratio of O_2 was in the massive wood samples impregnated with sodium tetra borate and the highest ash ratio in laminated samples impregnated with sodium perborate (Uysal and Özçifçi 2004).

The aim of this paper is to investigate the combustion properties and emission testing of LVL manufactured from mulberry. The LVL samples were impregnated with di-ammonium phosphate, aluminium sulphate, potassium carbonate, calcium chloride, and zinc chloride using pressure – vacuum method.

MATERIAL AND METHODS

Wood Material

Wood is commonly divided into two main groups: softwood and hardwood. These names do not refer to strength or density of the wood as is commonly assumed. Mulberry (*Morus alba* L.) widely used in decoration and interior design was used in LVL production. The test samples were chosen randomly from timber suppliers in Ankara, Turkey. Special emphasis was given for the selection of the wood material. Accordingly, non-deficient, proper, knotless, normally grown wood materials (without zone line, without reaction wood and without decay, insect and fungal infections) were selected.

Adhesive

The following adhesives were used in this experiment: PVAc an odorless, non-flammable adhesive 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 its bonding resistance capacity over 70 °C. Using 150–200 g.m⁻³ the adhesive seems to be suitable on condition that it is applied to only one surface (Ors 1987).

TS 3891 standard procedure was used for applying PVAc adhesive. The density of PVAc should be 1.1 g.cm⁻³, 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 with 6–15 % humidity is recommended for the jointing process. After a hot-pressing process, the materials should be attended until their normal temperature is reached (TS 3891 1983). PVAc adhesive was supplied from POLISAN, a producer firm in İzmit, Turkey.

The building blocks of 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 product plants as a colloidal aqueous solution with a solid content between 30 % (for LVL) and 50 % (for HB and OSB). This liquid is odourless, 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 is bonded permanently within the three-dimensional cross-linked PF network (Colakoğlu 1998).

Impregnation Chemicals

As impregnation chemicals; di-ammonium phosphate, aluminium sulphate, potassium carbonate, calcium chloride, zinc chloride were used.

Impregnation Process

In the impregnation process pressure - vacuum method has been applied.

Before and after the impregnation and after the test samples were kiln dried, the amount of retention (R, kg.m⁻³) and ratio of retention (R %) was calculated as follows;

$$R = \frac{GxC}{V} 10^3 \text{ kg.m}^{-3} \qquad R = \frac{M_{di} - M_d}{M_d} 100 \quad (\%) \qquad (1, 2)$$

Where:

- $G = T_2 - T_1$ $T_2 =$ Mass of the sample after the impregnation (kg)
 $T_1 =$ Mass of the sample before the impregnation (kg)
 $M_{di} =$ Oven dry mass of the samples after the impregnation (kg)
 $M_d =$ Oven dry mass of the samples before the impregnation (kg)
 $V =$ Volume of the sample (cm^3)
 $C =$ Concentration percentage of the solution (%)

Impregnation test plan is given in Tab. 1.

Tab. 1: Impregnation test plan

Test No	Impregnation chemicals	Sample humidity (%)	Solution concentration (%)	Solvent
1	Control	12	-	-
2	Natural	12	-	-
3	Di-ammonium phosphate	12	10	Pw
4	Aluminium Sulphate	12	10	Pw
5	Potassium carbonate	12	10	Pw
6	Calcium chloride	12	10	Pw
7	Zinc chloride	12	10	Pw

Pw: Pure water

Preparation of Test Samples

The test samples were climatized until they were stable at 20 ± 2 °C and with 65 ± 3 % relative humidity in climate room. Later on they were cut with the dimensions of $3 \times 22 \times 1030$ mm³ and bonded with phenol-formaldehyde (PF) and poly (vinyl acetate) (PVAc) as 3 layered LVLs ($9 \times 19 \times 1016$ mm³) according to the procedure of ASTM E - 69. 10 samples were manufactured for each test sample (lamina control, massive wood and lamina) 130-test samples were prepared in total (Fig 1).

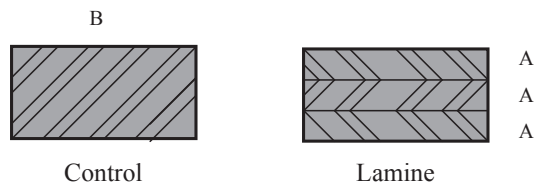


Fig. 1: Lamina test samples ($A = 3$ mm. $B = 19$ mm)

Execution of the Test

The combustion test was carried out according to the principles of the ASTM E - 69 (ASTM-E 69 1975). But some changes were made in the stand of the combustion. For this purpose, a digital balance with 0.01 g sensitiveness has been used for determination of the mass reduction of materials when they are burnt. Butane gas was used to make an ignition flame. According to the gas flow standard where the height of the flame is 25 cm, the temperature must be 1000 °C. The distance, between the bottom of the test samples hung inside 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 (CO , NO_x , SO_2 , O_2) 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 the combustion test flame source was kept for 4 minutes then flame source was taken away and it was continued for 6 minutes. The test lasted totally for 10 minutes. The schematic arrangement of apparatus can be seen in Fig. 2.

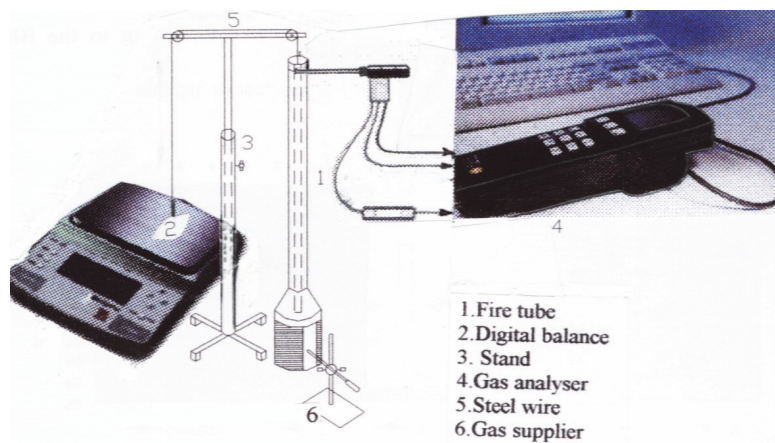


Fig. 2: Schematic arrangement of apparatus

Testo 300 M and XL flue gas analyser was used for measuring the concentration of the released gasses (CO , NO_x , SO_2 , O_2), and temperature variations.

Statistical Procedure

Multi variance analysis was applied to determine both the amount of retention in the prepared natural and laminated samples and the effects of impregnation material on combustion with or without flame source. Concerning the Duncan test each significant test group was compared with one another and itself.

RESULTS AND DISCUSSION

Peculiarities of the Solution

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

Tab. 2: Peculiarities of Impregnation Chemicals

Impregnation Chemicals	Purity %	Temperature (°C)	pH		Density (g.ml ⁻¹)	
			BI	AI	BI	AI
Di-ammonium phosphate	99	23	8	8	1.090	1.140
Aluminium sulphate	98	23	3.50	3.50	1.080	1.080
Potassium carbonate	99	23	12	12	1.190	1.190
Calcium chloride	97	23	7	7	1.120	1.130
Zinc chloride	99	23	6	5.5	1.120	1.130

BI: Before impregnation AI: After impregnation

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 values of aluminium Sulphate with 3.5 % solution's being in the acidic zone may be effectual on polysaccharide of the wood.

Retention

The proportion of impregnation chemicals is given in Tab. 3.

The highest retention proportion was obtained from the di-ammonium phosphate and the lowest from the aluminium sulphate.

Tab. 3: Proportion of retention

Test no	Impregnation chemicals	Retention (%)	
		\bar{X}	HG *
1	Control	-	-
2	Natural	-	-
3	Aluminium sulphate	1.52	A
4	Potassium carbonate	4.25	B
5	Zinc chloride	5.55	C
6	Calcium chloride	9.12	D
7	Di-ammonium phosphate	11.32	E

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

Air Dry Density

The average densities of LVL samples with 12 % humidity are given in Tab. 4. The highest density was observed in the laminated wood samples impregnated with di-ammonium phosphate. Concerning the control samples, it is possible to say that impregnation chemicals and glue increased the density of LVLs.

Tab. 4: Air dry density of wood samples ($g \cdot cm^{-3}$)

Samples	δ_{12}	δ_{12}
	(With PVAc)	(With PF)
I- Control	0.65	
II- Lamina control	0.70	0.74
III- Lamina $Al_2(SO_4)_3$	0.71	0.75
IV- Lamina K_2CO_3	0.73	0.77
V- Lamina $ZnCl_2$	0.74	0.78
VI- Lamina CaCl	0.76	0.80
VII- Lamina $(NH_3)_2P$	0.78	0.82

Values of Combustion

Obtained average values concerning the impregnation chemicals are given in Tab. 5.

The multi variance analyse applied on the data obtained from the combustion test is given in Tab. 6. Concerning the variance analysis, impregnation type and measure of time on mass reduction, temperature and released gas (CO , NO_x , SO_2 , O_2) were statistically significant. The interaction between the 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 Tab. 7 and 8.

Tab. 5: Average combustion values of impregnation chemicals

		Cont.	PVAc Lamina						PF Lamina					
After the Combustion Measured Values	Impreg. chemicals	Wood control	LVL control	(NH ₃) ₂ P	Al ₂ (SO ₄) ₃	K ₂ CO ₃	Cacl	Zncl ₂	LVL control	(NH ₃) ₂ P	Al ₂ (SO ₄) ₃	K ₂ CO ₃	Cacl	Zncl ₂
	CO	1185	1053	429	432	657	675	512	1392	326	551	402	522	505
	NO _x	21.62	22.70	32.8	10.77	16.00	10.47	8.25	27.32	23.85	22.00	8.55	16.60	13.82
	SO ₂	16.30	3.20	23.57	1.52	7.20	4.72	11.87	2.15	1.10	3.60	0.20	2.62	1.62
	Temp.	284	315	182	223	203	195	139	283	173	208	154	170	235
	O ₂	17.8	16.7	18.9	18.8	18.6	18.6	19.2	16.8	19.2	18.5	20.1	18.9	18.5
	Mass reduct. (%)	30.09	18.64	20.18	25.36	21.84	13.51	8.27	11.93	9.63	14.64	8.58	6.00	14.97

Tab. 6: The multy variance analyze connected with adhesive type, impregnation type, find of value and measured of time

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
A	17988.526	2	8994.263	0.342	0.71
B	8046336.828	5	1609267.366	61.219	0.00
C	18125209.524	19	953958.396	36.290	0.00
D	129719789.849	5	25943957.970	986.945	0.00
A * B	909505.858	5	181901.172	6.920	0.00
A * C	2029909.557	38	53418.673	2.032	0.00
B * C	64499.520	10	6449.952	0.245	0.04
A * B * C	8422914.166	95	88662.254	3.373	0.00
A * D	29604385.073	25	1184175.403	45.048	0.00
B * D	52991594.228	95	557806.255	21.220	0.00
A * B * D	1537101.152	95	16180.012	0.616	0.99
C * D	3927498.264	25	157099.931	5.976	0.00
A * C * D	9658247.862	190	50832.883	1.934	0.00
B * C * D	35752128.202	475	75267.638	2.863	0.00
A * B * C * D	7315456.822	475	15400.962	0.586	0.99

Factor A = Adhesive type (PVAc and PF)

Factor B = Impregnation type (Al₂(SO₄)₃., K₂CO₃, Cacl, Zncl₂, (NH₃)₂P)

Factor C = Find of value (CO, NO_x, SO₂, temperature, O₂, Mass reduction)

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

Tab. 7: Duncan test results of LVL ($p \leq 0.05$)*.

Source of Variance	CO (ppm)	NO _x (ppm)	SO ₂ (ppm)	Temp. (°C)	O ₂ (%)	Mass reduct. (%)
Pf-(NH ₃) ₂ P	326.37a	23.85cde	1.10a	173abc	19.2bcd	9.63abc
Pf- K ₂ CO ₃	402.80ab	8.55a	0.20a	154ab	20.1d	8.58abc
PVAc-(NH ₃) ₂ P	429.30ab	32.85e	23.57d	182abc	18.9bcd	20.18f
PVAc- Al ₂ (SO ₄) ₃	432.12ab	10.77ab	1.52a	223bcd	18.8bcd	25.36g
Pf- Zncl ₂	505.80ab	13.82abc	1.62a	235cd	18.5bc	14.97de
PVAc- Zncl ₂	512.95ab	8.25a	11.87bc	139a	19.2cd	8.27ab
Pf- Cacl	522.07ab	16.60abcd	2.62a	170abc	18.9bcd	6.00a
Pf- Al ₂ (SO ₄) ₃	551.85ab	22.00bcde	3.60a	208abcd	18.5bc	14.64de
PVAc- K ₂ CO ₃	657.02b	16.00abcd	7.20ab	203abc	18.6bc	21.84fg
PVAc- Cacl	675.80b	10.47ab	4.72a	195abc	18.6bc	13.51cd
PVAc-Control	1053.27c	22.70cde	3.20a	315e	16.7a	18.64ef
Massive Control	1185.15cd	21.62bcde	16.30c	284de	17.8ab	30.09h
Pf-Control	1392.05e	27.32de	2.15a	283de	16.8a	11.93bcd

Tab. 8: Duncan test results of LVL with measured of time ($p \leq 0.05$)*.

Measured of time	CO (ppm)	NO _x (ppm)	SO ₂ (ppm)	Temp. (°C)	O ₂ (%)	Mass reduct. (%)
	x	x	X	x	x	x
1	265.15a	15.92cde	5.73abc	187bc	17.6e	0.3a
2	351.26ab	20.76ef	6.26abc	223cd	17.0de	0.7a
3	502.03abc	30.11fg	6.84abc	258d	16.3cd	1.5a
4	640.03bcd	38.15gh	9.61abc	323ef	15.4bc	3.3ab
5	922.88def	49.34i	13.50bcd	388g	14.4a	5.6ab
6	1067.88efg	45.46hi	14.69cd	428g	14.9ab	8.0bc
7	1416.65h	49.88i	19.26d	430g	15.4bc	11.2cd
8	1265.19gh	29.61fg	12.80bcd	375fg	17.0de	15.1de
9	1231.80fgh	19.34de	9.42abc	279de	19.1f	17.8ef
10	874.38de	14.26bcde	7.50abc	219cd	19.3f	19.3efg
11	750.53cde	11.26abcde	4.96abc	214cd	19.4fg	20.4fg
12	644.46bcd	9.38abcd	3.80ab	144ab	20.0fgh	21.0fg
13	535.46abc	7.80abc	2.69a	125ab	20.4gh	21.8fg
14	489.26abc	6.26abc	1.76a	114a	20.4gh	22.4fg
15	469.23abc	3.61ab	0.84a	109a	20.4gh	23.1fg
16	437.23abc	2.84a	0.76a	101a	20.5gh	23.7g
17	411.15abc	2.00a	0.57a	95a	20.6h	23.8g
18	380.65ab	1.80a	0.50a	88a	20.6h	24.1g
19	351.11ab	1.73a	0.50a	82a	20.6h	24.4g
20	296.00ab	1.65a	0.53a	75a	20.6h	24.9g

* 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 zinc chloride. The results connected with these values are shown in Fig. 3.

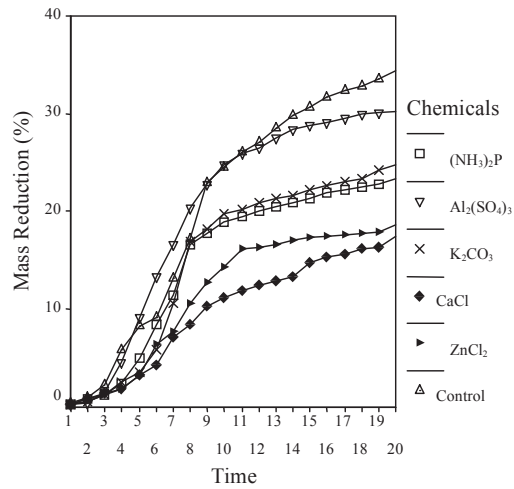


Fig. 3: The mass reduction (%)

As a result of combustion, the highest reduction of O₂ concentration was measured in massive control samples and the lowest change of O₂-concentration in the combustion of LVLs, with PF adhesive and impregnated with potassium carbonate. Inorganic materials act as heat sink lowering the efficiency of combustion. Also, inorganic materials favour the formation of char. The results connected with these values are shown in Fig. 4.

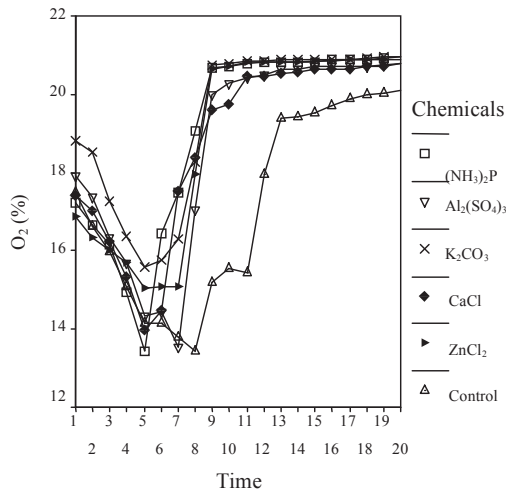
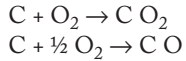


Fig. 4: O₂-ratio in the combustion gases (%)

The concentration of oxygen remained almost constant after the start of the combustion with all other samples except from the control sample. The proportion of oxygen is 21 % in air normally. So the treated samples have reacted very slowly with oxygen and burned poorly.

Impregnation chemicals had fire retardant effects when they were compared with 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 temperatures 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 LVL samples with PVAc adhesive and impregnation unprocessed and the lowest in those of LVL samples with PF adhesive and impregnated with zinc chloride. The results connected with these values are shown in Fig. 5.

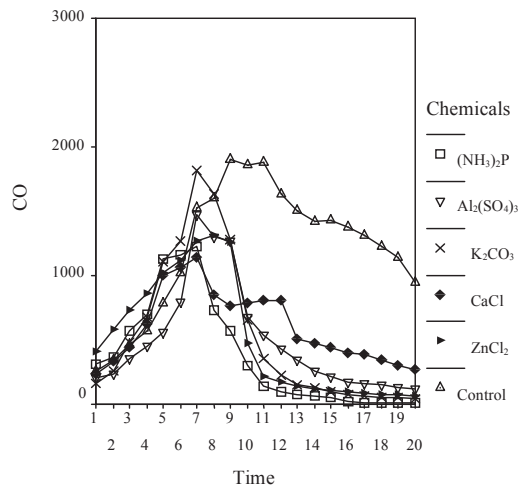
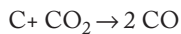


Fig. 5: Variation of CO Ratio (ppm)

There is no important change in the proportion of CO in the test samples due to the flame source at the first stage of the combustion. As a result of moving the flame source from the fire tube (for 3-4 minutes after the start of the combustion), a linear motion was observed in impregnated samples at the stage of the inflame source combustion. As for control samples, except for LVL samples with PF adhesive and impregnation unprocessed, there was an important change in the ratio of CO because of the combustion's going on at the stage of inflame source combustion. Concerning the control samples, impregnation chemicals decreased the occurrence of CO by diminishing the combustion. At very high temperature no oxygen reaches the carbon and therefore it burns in CO_2 according to the following reaction equation:



The highest temperature variation was observed in massive control samples and the lowest in LVLs with PF adhesive and impregnated with di – ammonium phosphate. The results connected with these values are shown in Fig. 6.

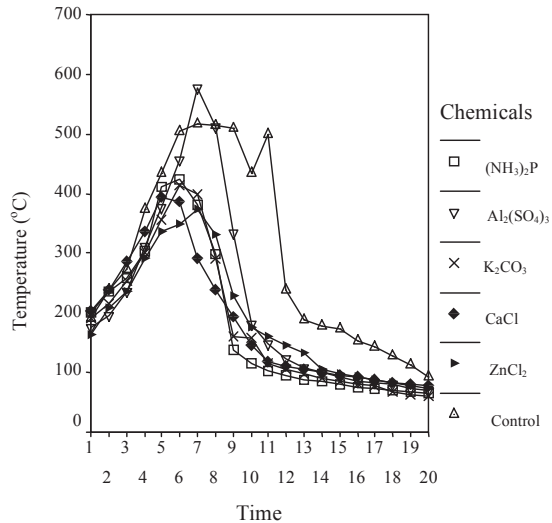


Fig. 6: Temperature Variation during the experiments (°C)

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 oxidise further (Lobert and Scharffe 1991).

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

The highest concentrations of SO₂ was observed in the LVL samples with PVAc adhesive and impregnation unprocessed and the lowest in the LVL control samples (massive wood) impregnated with potassium carbonate and zinc chloride. The results connected with these values are shown in Fig. 7.

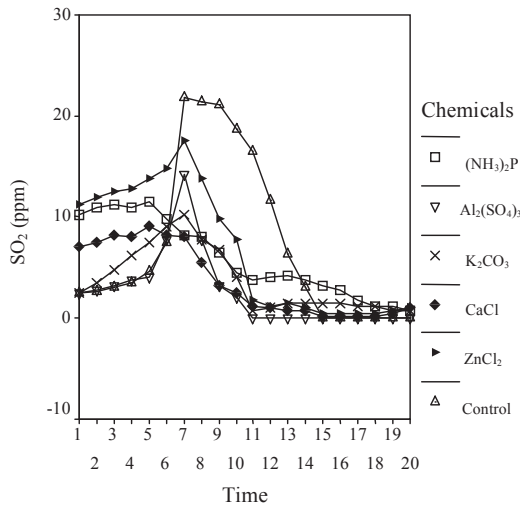


Fig. 7: Variation of the SO₂ (ppm)

In this study, the highest increase in NO_x concentration was observed in the experiment of LVL samples with PVAc adhesive and impregnation unprocessed and the lowest in those of LVL control samples (massive wood) impregnated with zinc chloride. The results connected with these values are shown in Fig. 8.

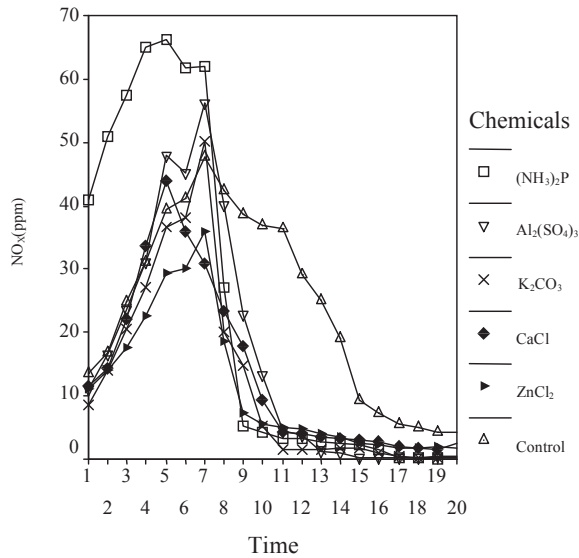


Fig. 8: Variation of the NO_x (ppm)

Concerning the control samples it can be said that impregnation chemicals have shown the effect of fire retardant. Control samples gave the highest concentration of CO₂.

CONCLUSION

During the first 4 minutes, at the first stage of the experiment, the combustion occurred nearly at the same time in all samples. After taking the flame source from the fire tube, the highest mass reduction (56.70 %) was observed in the LVL samples with PVAc adhesive and impregnated with aluminium sulphate at the second stage of combustion. Insoluble compounds act as a heat sink lowering the efficiency of combustion but soluble ionic compound can have a catalytic effect on the pyrolysis and the combustion of the wood (Shafizadeh 1981).

At the end of the combustion test, the most average consumption ratio of O₂ was seen in the LVL samples (16.7 %) with PVAc adhesive and impregnation unprocessed. The lowest average consumption ratio of O₂ was observed in the LVL samples with PF adhesive and impregnated with potassium carbonate with the ratio of 20.1 % O₂.

The highest ratio of CO was observed in the LVL samples (1392 ppm) with PF adhesive and impregnation unprocessed and the lowest in the LVL samples with PF adhesive and treated with diammonium fosfate (326 ppm). As well known, there are two forms of reaction between C₂ and O₂ during the combustion. The ratio of the combustion of a sample is directly connected to the sum of the amount of CO and CO₂ emissions. Because the combustion tests are made in an open environment, there is not lacking of O₂ and poor mixing. Both the amounts of CO and CO₂ emissions of the LVL samples used in the test, with PVAc adhesive and treated by zinc chloride are lower than the LVLs and wood control samples. It is possible to say that impregnation chemicals have fire retardant effect.

Due to the fire resource, at the first stage of the combustion test, a linear increase was observed in the temperature variation. The temperature of the impregnated LVL samples with PF and PVAc adhesive and impregnated wood control samples decreased when the fire source was taken away from the fire tube.

The highest concentrations of SO₂ were observed in the LVL samples (23.57 ppm) with PVAc adhesive and impregnated with di-ammonium phosphate and the lowest in the LVL samples (0.20 ppm) with PF adhesive and impregnated with potassium carbonate.

The highest increase in NO_x concentration was observed in the experiment of the LVL samples (32.8 ppm) with PVAc adhesive and impregnated with di-ammonium phosphate and the lowest in those of the LVL samples with PVAc adhesive and impregnated with Zinc chloride (8.25 ppm).

Di-ammonium phosphate ranked first in reducing the 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 1984).

As a result; zinc chloride was found to be the most successful fire retardant chemical in LVL with PF adhesive. Since zinc chloride diminishes combustion, LVL produced from mulberry by using PF adhesive and impregnated with zinc chloride can be advised to be used as a fire resistant building material where required.

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