THE DETERMINATED COMBUSTION PROPERTIES OF FIR WOOD IMPREGNATED WITH FIRE-RETARDANTS

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Abstract: In this study, the effects of impregnation material and impregnation methods on combustion properties of Fir (Abies bornmulleriana, Mattf.) have been investigated. The four different method was used for impregnation process. Combustion test was performed according to the procedure of ASTM-E 69 standards. According to the test results fire retardant materials and impregnations methods was found to be the most successful fire retardant chemical and long-term dipping method in Fir.
Key words: Fir, Dipping method, Fire Retardant

Introduction

Wood has many good properties from the point of view of processing, physical and mechanical properties, aesthetic, environmental and health aspects. In many countries the wood is widely used as building material, in some areas as main construction and decoration material. 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 (Bednarek and Kaliszuk, 2007). Wood is a naturally durable material that has been recognized for centuries throughout the world for its versatile and attractive engineering and structural properties. It is well known that there are possibilities to improve significantly the fire performance of wood by chemical treatment and to widen its application options. In general the amount of flame retardant uptake to the wood is directly proportional to the improvement of reaction to fire characteristics [Balog, 1986). Important reactions to fire parameters in the full scale fire are heat release rate and time of flashover (Babrauskas and Grayson, 1992). Flame retardant treated materials may have much better fire performance concerning these parameters than untreated wood products. Combustion of wood involves a complex series of physical transformations and chemical reactions that are further complicated by the heterogeneity of the substrate. Wood, and cellulosic materials in general, do not burn directly; under the influence of sufficiently strong heat sources they decompose to a mixture of volatiles, tarry compositions, and highly reactive carbonaceous char. Gas-phase oxidation of the combustible volatiles and tarry products produces flaming combustion. Solid-phase oxidation of the remaining char produces glowing or smoldering combustion, depending on the rate of oxidation (Baysal, 1994). Wood coatings more often are designed to retard ignition and rate of burn rather than to provide the fire-resistive barrier which is more typical of steel coatings. Typically, coatings protective (or retardant) against cellulosic-type fires are applied in thin film coat sup to 1.5 mm (60mils) thick. These coatings are usually not very weatherable; so, for outdoor applications, a protective topcoat is needed (Shafizadeh, 1984). Uysal et al. (2008) investigated the effects of finishing materials polyurethane, cellulosic, synthetic, polyester, and acid hardening varnish on combustion properties of Scotch pine. Cellulosic varnish was found to be the most successful varnish according to the CO amounts and mass reduction. According to their results, all of the varnishes used to in their study showed a low resistance against fire and high temperatures. Uysal and Kurt (2005) studied the impregnation of the oriental spruce (*piceaorientalis L.*) with boron compounds, and the test samples were applied to the combustion test. A borax-boric acid % 10 solution was found to be the most successful fire retardant chemical. Kurt and Uysal (2009) investigated the effects of fire retardant materials zincchloride and di-ammonium phosphate were found to be the most success full fire- retardant chemicals in LVL. Since it diminishes combustion, the impregnation of LVL produced from walnut by using PF and PVAc adhesives can be advised to be impregnated by using the pressure-vacuum method. The aim of this paper is to investigate the combustion properties and emission testing of Uludag fir, widely used in building construction. The samples were impregnated with firetex produced by kale natural using 3 different dipping method.

Material and Method

Wood Material

Uludag fir (Abies bornmülleriana Mattf.) was used. 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.

Impregnated Materials

Firetex is an effective, natural, non-toxic, ecologic and economic water based fire-retardant and fire-extinguisher. The properties of some physical are given in Table 1.

Table 1. Physical Properties of firetex

Boiling point	98 ºC
Freezing point	-3 ºC
pH	3,7
TDS	739 ppm
Evaporation (60 ˚C / 24 h)	% 50

Preparation of Test Samples

The oversized test samples were acclimatized until they were stable at 20 ± 2 ºC and 65 ± 3 % relative humidity in climate room. Later on they were cut with the dimensions of 9x19x1016 mm^3 according to the procedure of ASTM E – 69.

Impregnation processes stated at ASTM D 1413-76, TS 344 and TS 345 were applied to the prepared test samples. For this aim, the samples were dipped into the impregnation solution (having packing viscosity) for 2 min, 24 h and 7 days, respectively, for short-term dipping, provided the samples passed over 1 cm of its upper surface and finished with fire retardant finishing. The peculiarities of impregnation were determined before and after impregnation processes. All processes were carried out at 20±2°C. The samples, oven dried before and after impregnation, can be calculated by the formula

$$R = \frac{GC}{V} \times 10^3 \text{ kg} / \text{m}^3,$$

where R is the retention of impregnation material, $G=T_2-T_1$, T_1 is the sample weight before impregnation (g), T_2 is the sample weight after impregnation (g), C is the concentration (%) and V is the volume of the samples (cm^3). Impregnated test samples were kept at 20±2°C and at 65±3% relative humidity until their weights became stable.

Execution Test

The combustion test was carried out according to the principles of the ASTME –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 high of flame is 25 cm, the temperature must be 1000 ºC. The distance between the bottoms of the test samples, which were hanged 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 (CO, NO, 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 combustion test flame source was used for 4 minutes then flame source was taken away and it was continued 6 minutes. Totally 10 minutes, the test was lasted.

Statistical Procedure

Descriptive statistics analysis was applied to determine both the amount of retention in the prepared natural and the effects of impregnation material on combustion with or without flame source.

Results and Discussion

The air dry density (0. 430 gr/cm^3) was obtained fir wood. The proportion of impregnation material is given in Table 2.

Table 2. Proportion of Retention

Test no	Impregnation Method	Retention (%)	
		$\overline{X}$	HG *
1	Finished with by a brush	6,6	A
2	Short-term dipping (2 min)	11,5	B
3	Middle-term dipping (24 h)	36,1	C
4	Long-term dipping (7 days)	52,8	D

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

The highest retention proportion was observed in dipping method of long time and the lowest in finished with a brush. The averages of mass reduction are given in Table 3.

Table 3. Average of Mass Reduction(%)

Measured of time	Control	Dipping method			with a brush
		2 min	24 hours	7 days	
1	3.06	5.29	1.75	2.45	7.62
2	6.59	7.41	4.57	3.86	12.51
3	10.88	11.60	5.74	6.28	15.42
4	16.91	14.32	7.95	7.76	17.27
5	25.42	17.15	10.64	9.48	18.16
6	35.47	20.66	12.48	10.26	19.26
7	44.92	22.12	13.61	11.42	19.75
8	51.34	24.63	14.92	13.61	20.14
9	59.16	26.24	16.86	15.57	20.86
10	65.74	27.96	17.95	16.12	21.47
11	76.32	33.65	21.64	18.00	22.74
12	84.12	36.42	22.30	19.54	24.51
13	88.46	39.25	24.61	20.16	25.84
14	91.15	41.42	25.49	21.33	27.18
15	94.05	42.16	27.56	23.76	29.38
16	95.10	43.41	29.18	24.37	32.14
17	96.22	44.67	31.46	25.01	33.44
18	97.34	45.23	31.98	25.38	34.16
19	97.75	45.69	33.25	25.76	35.28
20	98.65	46.12	33.70	26.24	35.69

The highest mass reduction was (%98.65) observed in control samples, the lowest value (%26.24) in the impregnated with firetex by long-term dipping method. The averages of O_2 amounts are given in Table 4.

Table 4. Average of O_2 amounts (%)

Measured of time	Control	Dipping method			With a brush
		2 min	24 hours	7 days	
1	20.02	20.12	20.05	20.37	20.24
2	19.41	19.82	19.75	20.01	19.88
3	19.1	19.67	19.66	19.84	19.55
4	18.83	19.53	19.58	19.68	19.25
5	18.58	19.29	19.36	19.57	19.16
6	18.65	19.21	19.46	19.49	19.05
7	18.57	19.59	19.49	19.67	19.35
8	18.36	19.74	19.70	19.79	19.48
9	17.91	20.11	19.85	19.90	19.76
10	18.13	20.41	19.92	20.63	19.99
11	18.2	20.50	19.99	20.92	20.38
12	18.47	20.88	20.36	20.97	20.82
13	18.94	20.91	20.78	20.97	20.97

14	19.54	20.94	20.88	20.98	20.98
15	19.71	20.95	20.97	20.98	20.98
16	20	20.97	20.98	20.99	20.99
17	20.33	20.97	20.98	20.99	20.99
18	20.57	20.98	20.99	20.99	20.99
19	20.69	20.99	20.99	20.99	20.99
20	20.72	20.99	20.99	20.99	20.99

The highest reduction of O_2 concentration (% 20.99) was measured in the impregnated with firetex by all of the dipping method. The lowest change of O_2-concentration (%17.91) in combustion of non-impregnated fir control samples**.** From the control samples it can be seen that the impregnation chemicals has the effect of fire retardant. Control samples gave the highest CO2 concentrations. The averages of temperature are given in Table 5.

Table 5. Average of Temperature Values(^{0}C)

Measured of time	Control	Dipping method			with a brush
		2 min	24 hours	7 days	
1	87.9	85.9	99.4	89.6	83.1
2	116.1	102.6	117.6	104.0	101.6
3	150.1	119.4	129.4	114.3	118.4
4	176.2	134.1	137.3	122.7	138.6
5	204.6	150.1	145.4	130.6	154.1
6	228.3	163.4	157.0	138.1	159.7
7	248	165.6	165.1	147.3	166.4
8	269.8	163.4	166.4	151.8	166.8
9	310.9	156.0	165.0	149.6	164.5
10	384.9	140.1	163.2	138.3	154.2
11	425.7	132.7	160.6	128.1	140.1
12	424.6	125.6	149.5	120.1	129.0
13	405.6	116.0	138.5	113.7	120.6
14	359.4	109.9	129.4	106.0	112.7
15	309.5	102.3	121.0	101.8	106.4
16	271.3	97.6	114.1	97.3	101.2
17	238.3	92.5	109.6	93.0	96.3
18	218.4	88.4	104.1	90.4	92.3
19	201.1	85.7	100.2	87.5	89.4
20	185.5	82.0	96.4	84.2	85.2
Mean	260.8	120.6	133.4	115.4	124.0

The highest averages temperature (260.8 ^{0}C) variation was observed in the fir control samples, the lowest (115.4 ^{0}C) in impregnated with firetex by long-term dipping method. The averages of variations of CO are given in Table 6.

Table 6. Variation of CO (ppm)

Measured of time	Control	Dipping method			with a brush
		2 min	24 hours	7 days	
1	36.7	79.3	86.3	50.2	90.5
2	70	131.3	156.4	118.4	128.4
3	92.1	152.4	178.7	142.6	157.7
4	107.5	163.1	184.9	154.8	173.1
5	148	174.0	186.0	162.4	179.2
6	264.3	189.0	194.1	175.1	185.3
7	414.8	195.2	160.5	190.0	216.0
8	484.9	209.6	156.0	167.4	212.7
9	487.3	229.9	145.7	153.7	154.4
10	437.5	179.4	112.5	111.8	120.6
11	309.5	148.5	101.2	91.7	84.1
12	317.9	132.6	93.3	53.9	52.9
13	282.7	110.4	51.4	28.4	26.2
14	204.7	108.9	23.6	11.2	13.0
15	254.1	102.7	10.4	4.3	10.1

16	233.1	79.0	7.3	3.7	7.3
17	183.3	49.2	5.9	3.1	5.4
18	116.4	18.6	4.7	2.5	4.1
19	70.2	5.1	3.4	2.2	2.5
20	58.3	2.5	3.0	1.9	1.1
Mean	228.7	123.0	93.3	81.5	91.2

The highest increase in CO concentration was (487.3ppm) observed in the control fir samples and the lowest in (1,1 ppm) impregnated with firetex by with a brush samples. The averages of variation of NO are given in Table 7.

Table 7. Variation of NO (ppm)

Measured of time	Control	Dipping method			with a brush
		2 min	24 hours	7 days	
1	0.4	8.1	14.7	17.4	8.7
2	1.3	7.5	12.5	14.5	7.9
3	1.9	6.4	9.7	12.7	7.5
4	3.2	5.5	8.8	9.1	7.2
5	3.9	5.1	8.4	8.0	6.6
6	3.3	4.8	7.7	7.4	6.2
7	3.5	4.2	6.7	7.1	5.4
8	4.3	3.7	6.2	6.5	4.6
9	4.9	3.4	5.0	6.0	4.2
10	6	2.7	4.4	5.7	3.5
11	6.5	2.5	4.1	5.2	2.6
12	6.5	2.3	3.8	3.9	2.2
13	5.7	2.0	3.7	3.7	1.9
14	4	1.7	3.5	3.2	1.6
15	3.3	1.5	2.7	2.5	1.4
16	2.7	1.1	2.6	2.1	1.3
17	1.5	0.9	2.4	1.8	1.1
18	0.5	0.7	2.1	1.4	0.8
19	0.3	0.4	1.8	1.2	0.5
20	0	0.2	1.4	1.0	0.3
Mean	3.2	3.2	5.6	6	3.8

In this study, the highest increase in NO concentration was observed in the experiment of (17.4 ppm) impregnated with firetex by long-term dipping method samples and the lowest in those of (0 ppm) non-impregnated control fir samples.

Conclusion

According to Table 3, after taking the flame source from the fire tube, the highest mass reduction (98.6 %) was observed in the non-impregnated control samples, the lowest in the impregnated with firetex by long-term dipping method fir samples (26.2 %) at the second stage of combustion. It has been observed that impregnated with firetex by long-term dipping method fir samples decreases mass reduction values 72. 4 % in average.

According to Table 4, the highest O_2 consumption was observed in the non-impregnated control samples (17,91 %). It been has observed that impregnated by short- term, middle-term, long-term dipping method fir samples impregnated with firetex samples decreases O_2 consumption values 3,09 % in average.

According to Table 5, the highest temperature was observed in the non-impregnated fir control samples (260,8 ºC). It been has observed that impregnated by long-term dipping method fir samples impregnated with firetex samples decreases ^{0}C consumption values 56 % in average.

According to Table 6, the highest ratio of CO was observed in the non-impregnated control samples (487.3 ppm). According to the averages values, it been has observed that impregnated by long-term dipping method fir samples impregnated with firetex samples decreases CO ratio values 64 % in average.

According to Table 7, the highest ratio of NO was observed in the impregnated with firetex by long-term dipping method samples (17,4 ppm). According to the averages values, it been has observed that impregnated by long-term dipping method fir samples impregnated with firetex samples increases NO ratio values 87 % in average. Consequently, fire retardant impregnated material was found to be the most successful according to the CO amounts and mass reduction. It can be proposed that protecting by dipping method or with a brush firetex of historical wooden structure due to fire risk.

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