Combustion Characteristics of Impregnated and Surface-treated Chestnut (*Castanea sativa* Mill.) Wood Left Outdoors for One Year

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Treating wood with impregnating materials in order to improve resistance to burning is a commonly employed safety measure. In this study, chestnut (*Castanea sativa* Mill.) wood samples were impregnated using either Tanalith-E or Wolmanit-CB according to ASTM-D 1413-76 and surface-treated using water-based or synthetic varnish according to ASTM-D 3023. These samples were used to investigate the combustion characteristics of samples left outdoors for one year as detailed in ASTM-E 160-50. The combustion temperatures of the samples left outdoors were similar upon impregnation with either Tanalith-E or Wolmanit-CB. However, the combustion temperature of the samples treated with synthetic varnish was lower than those that were treated with water-based varnish. The time to collapse and the total duration of combustion of the samples left outdoors were shorter for those impregnated with Wolmanit-CB. Weight loss of the samples left outdoors was higher for those that were impregnated with Tanalith-E and treated with water-based varnish. Gas analysis of the samples that were left outdoors indicated that the O_2 content of flue gas from samples that were impregnated with Wolmanit-CB and treated with synthetic varnish was high and the CO content of flue gas from the same samples was low.

Keywords: Combustion; Chestnut; Impregnated; Varnish; Gas Analysis; Wood

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INTRODUCTION

Wood is widely used as a building material. It has good properties relative to other materials that are used for this goal, but it is affected negatively by abiotic and biotic pests as well as fire (Peker *et al.* 1999). Wood is used in outer and inner space for structural and decoration elements (Peker 1997; Sönmez and Budakçı 2004). The use of wood continues to increase, which may be attributed to its high strength, relative lightness, ease of workability, and its ability to hold nails and screws (Aslan 1998).

The uses of wood material can be extended through impregnation. Suitable impregnation agents can include water repellants, biotic and abiotic chemicals, and varnishes to protect the wood against photochemical degradations, changes in size, biological degradation, and against fire damage rather than employing superficial

methods which would only last for shorter periods (Williams *et al*. 1996). Wood has to be treated with preservative chemicals (impregnation) in order to prevent damages that might occur and to prolong its lifetime (Richardson 1987).

Moreover, wooden and wood-based materials are inflammable due to the fact that they are comprised of carbon and hydrogen (Chin-Mu and Wang 1991). Wooden material is easily combustible and flammable. Fire-retardant impregnites go into degradation below the degradation temperature of wooden material and rapidly transform cellulose into wood charcoal and water. Thus, volatile and flammable materials that would have been formed in higher temperatures are not formed, leading to reduced inflammation of the wood; also any flames are prevented from spreading around (Le Van and Winandy 1990).

The aim of this study was to determine the effects of weathering on combustion of impregnation and surface treatment materials applied to *Castanea sativa* Mill. wood, which requires protection for indoor and outdoor applications, on its combustion characteristics.

EXPERIMENTAL

Materials

Samples of Anatolian chestnut wood were used in this study. Care was taken to choose resin-free, regular-fibred, knot-free, stably-grown samples. The randomly selected timber was acclimatized at a temperature of 20 ± 2 °C and relative humidity of 65 ± 3% until it achieved constant moisture content of 12% prior to coarse cutting.

Wolman it-CB and Tonality-E impregnation agents were obtained from Esan Impregnate Corporation and from Bilge Wood Corporation, Ankara, Turkey. Moreover, Wolman it-CB and Tonality-E are manufactured by Drs. Wolman and Hemel, respectively. Synthetic varnish and water-based varnish were supplied from Bayraktar Corporation, Ankara, Turkey. Furthermore, the varnish products are manufactured by Marshall-Wood Art and Jansen-Aqua Compact Lasur, respectively.

Methods

The experimental samples were cut to 13 × 13 × 76 mm (radial × tangent × length). Test samples were prepared from Anatolian chestnut wood to investigate the effect of two different impregnating materials and two different types of varnish (Water-based and synthetic varnish). Synthetic varnish is frequently used for both outdoor and indoor applications. Water-based varnish, unlike synthetic and polyurethane varnishes, does not release volatile gases harmful for human health. For the yearly (wood samples were subjected to weathering for one year) and control samples, there were three groups in each test period and 24 samples in each group. The test samples were dried at 20 ± 2 °C and a relative humidity of 65 ± 5% until they reached constant weight prior to impregnation. Weights were determined to a precision of 0.01 g.

The vacuum-pressure method was employed for impregnation as stated in ASTM-D 1413-76 (1976). To accomplish this, specimens were vacuumed under pressure equivalent to 600 mm Hg for 60 min and then placed in a solution under standard atmosphere pressure for 60 min. The impregnated materials were left in an air-circulated room for 15 to 20 days to allow for the evaporation of the solvent material and were kept at a temperature of 20±2 °C and relative humidity of 65±3% until they achieved constant

humidity of 12%. The samples were varnished following impregnation and acclimatization in compliance with the principles provided in ASTM-D 3023 (1988). Manufacturer's recommendations regarding the amount of varnish to be applied were followed. The varnish was weighed on a scale with a precision of 0.01g. Hardeners, thinners or diluting media needed to condition the varnish were employed in compliance with the recommendations of the manufacturer. The varnished samples were dried at room temperature. Varnished test samples were left outdoors on test stands at an angle of 45° facing south. The effects of outdoor conditions on the combustion characteristics of wood were investigated (Fig. 1.). The test samples were removed from the outdoor environment at the end of one year and the combustion characteristics of the samples were determined as detailed in ASTM-E 160-50 (1975).

Fig. 1. Images of samples used in the experimental study

The extent of retention of the impregnating material was determined as detailed in TS 5724 (1988), which was 2.47 and 2.90 kg/m^3 in chestnut samples that were treated with Tonality-E and Wolman it-CB, respectively.

Each sample group was weighed prior to burning and stacked on a gauze tripod. The 24 samples were stacked in 12 levels so as to form a tetragonal prism and were burned in the test. The source of flame was centered directly beneath the stack, which was burned for 3 min to maintain burning process with the flame. Then the source was extinguished to allow burning without flame and the afterglow stages. The impregnated and varnished with non-impregnated and unvarnished samples were removed from the outdoor environment at the end of their periodic exposure, and the burning characteristics of the samples were determined using the apparatus as detailed in the ASTM-E 160–50 standard. The temperature of combustion, illuminance, duration of combustion, weight loss, and the results of gas analyses of the instances (all measured in triplicate) were used to conduct an analysis of variance, employing a randomized block factorial experimental design using SAS software. The mean values were compared using the LSD test. Finally, a multiple correlation analysis was carried out in order to investigate the relationships between groups (SAS 1989). A correlation value in the range of 0.75 to 1.00 in the multiple correlation analysis was considered high.

RESULTS AND DISCUSSION

Values of Wood Samples in Combustion

The results of the analysis of variance of the effect of weathering type of impregnating material, and the type of varnish on the temperature of combustion, illuminance, and the duration of combustion of cedar wood during combustion with (CWF) or without flames (CWOF) and during afterglow (CDA) are presented in Table 1. In regards to the effects of different treatments on the combustion parameters, the weathering effect on temperatures of combustion were determined to be significantly different at a threshold of 1% during CWF and CWOF. The effect of varnish type was significant at a threshold of 1% and 5% during CWF and CWOF, respectively. Additionally, the effect of the type of impregnating material employed was significant at a threshold of 1% and 5% during CWOF and CWF, respectively. The weathering variation in illuminance was determined to be significant at a level of 1% and 5% during CWF and CWOF and the variation in impregnating materials at a level of 1% during CWOF. The weathering variation of illuminance was determined to be significant at a level of 5% during CDA. The differences in time to collapse and total duration of combustion were significant at a level of 1%.

Table 1. Results of the Analysis of Variance of Wood Samples in Combustion

Source of Variance		F.D.	S.S.	S.M.	F.V.	F.D.	S.S.	S.M.	F.V.
		Values of Temperature (ºC)				Values of Illuminance (lüx)			
Combustion With Flame (CWF)	pt	1	2128.17	2128.17	8.34*	1	28.17	28.17	9.94*
	vt	2	3906.48	1953.24	7.65*	2	12.0	6.00	2.12
	im	2	2203.82	1101.91	4.32**	2	5.44	2.72	0.96
	pt*im	2	430.11	215.06	0.84	2	13.0	6.50	2.29
	pt*vt	2	1522.11	761.06	2.98	2	13.78	6.89	2.43
	im*vt	4	2915.85	728.96	2.86**	4	68.89	17.22	6.08*
	pt*im*vt	4	2768.44	692.11	2.71**	4	36.22	9.06	3.20**
	Error	36	9188	255.22		36	102	2.83	
	Total	53	25062.98			53	279.50		
Combustion Without Flame (CWOF)	pt	1	29260.17	29260.17	129.6*	1	16.67	16.67	4.27**
	vt	2	1826.70	913.35	4.05**	2	14.82	7.41	1.90
	im	2	5445.15	2722.57	12.06*	2	58.93	29.46	7.54*
	pt*im	2	14.78	7.39	0.03	2	42.11	21.06	5.39*
	pt*vt	2	374.11	187.06	0.83	2	5.78	2.89	0.74
	im*vt	4	1849.63	462.41	2.05	4	33.30	8.32	2.13
	pt*im*vt	4	2650.44	662.61	2.93**	4	48.78	12.19	3.12
	Error	36	8128	225.78		36	140.67	3.91	
	Total	53	49548.98			53	361.04		
Combustion During Afterglow (CDA)	pt	1	6186.84	6185.74	3.80	1	11.57	11.57	4.84**
	vt	2	4814.70	2407.35	1.48	2	30.78	15.39	6.44*
	im	2	9025.93	4512.96	2.78	2	10.11	5.06	2.12
	pt*im	2	9945.48	4972.74	3.06	2	18.04	9.02	3.78**
	pt*vt	2	35281.59	17640.80	10.85*	2	18.04	9.02	3.78**
	im*vt	4	10144.07	2536.02	1.56	4	18.11	4.53	1.90
	pt*im*vt	4	18471.85	4617.96	2.84**	4	36.19	9.05	3.79**
	Error	36	58536.67	1626.02		36	86	2.39	
	Total	53	152407.04			53	228.83		
		Value of Time to Collapse (CTV) (sn)				*Total Time of Combustion (CTT)(sn)*			
Time of Combustion (CT) (sn)	pt	1	24533.35	24533.35	145.6*	1	343044.7	343044.7	48.75*
	vt	2	503.26	251.63	1.49	2	26955.44	13477.72	1.92
	im	2	437.37	218.69	1.30	2	34730.11	17365.06	2.47
	pt*im	2	349.37	174.69	1.04	2	81192.26	40596.13	5.77*
	pt*vt	2	2600.15	1300.07	7.72*	2	113849.37	56924.69	8.09*
	im*vt	4	2766.85	691.71	4.11*	4	58150.44	14537.61	2.07
	pt*im*vt	4	2419.96	604.99	3.59**	4	65198	16299.57	2.32*
	Error	36	6064.67	168.46		36	253346.67	7037.41	
	Total	53	39674.98			53	976467.33		

F.D.: degrees of freedom, S.S.: sum of squares, S.M.: mean of squares, F.V.: F value, pt: types of process, vt: types of varnish, im: materials of impregnate

The mean values and the results of the LSD test are given in Table 2. The maximum mean temperatures of combustion were 502 °C CWF, 628 °C CWOF, and 341 °C CDA for the weathering effect, with the control values being the highest. Regarding the impregnating materials, the mean temperatures of combustion were 504 °C CWF, 616 °C CWOF, and 367 °C CDA when Wolmanit-CB was employed as the impregnating material and 489 °C CWF, 592 °C CWOF, and 336 °C CDA when Tanalith-E was employed as the impregnating material. In regards to varnish type, water-based varnished yielded the highest values with 496 °C CWF, 604 °C CWOF, and 350 °C CDA, compared to synthetic varnish, which yielded 486 °C CWF, 598 °C CWOF, and 341 °C CDA. The illuminance values during combustion of impregnated cedar wood with or without flame or during afterglow were very similar across the different weathering effects, impregnating materials, and varnishes (Table 2).

The longest time to collapse CTV was 379 s and the total time of combustion CTT was 728 s for the control samples with respect to the seasonal effect. The CTV was 354 s, and CTT was 615 s for the effect of the employment of Wolmanit-CB, which was lower than the values for Tanalith-E application 360 s CTV and 656 s CTT. The values for water-based or synthetic varnish application were 362 s CTV and 656 s CTT or 355 s CTV and 672 s CTT, respectively, indicating similar durations (Table 2).

For chestnut wood, the highest temperature of combustion was measured from the control samples with respect to the weathering changes during combustion with and without flame. Wood samples that were impregnated with Wolman it-CB were measured the highest from Tonality-E during combustion with, without flame, and afterglow. Likewise, water-based varnish was the highest from synthetic varnish.

The illuminance values, which were determined for the impregnated chestnut wood samples, were similar with respect to weathering variations, the type of impregnating material, and the type of varnish employed during combustion with or without flame and during afterglow.

The measured combustion parameters indicated that the longest time to collapse and the longest total duration of combustion were observed in control materials. The time to collapse and the total duration of combustion were shorter for samples that were impregnated with Wolmanit-CB than those that were impregnated with Tanalith-E. The two types of varnish were not significantly different from one another in terms of time to collapse or duration of combustion.

In a conducted study in the literature, regarding the measured average temperature °C values as a result of combustion test: the highest value was obtained in Tanalith-E impregnated and water-based varnish coated specimens, the lowest value in boric acid impregnated and polyurethane varnish coated specimens (Uysal *et al.* 2011). Data obtained when comparing test specimens show similarities with the findings in literature.

Table 2. Mean Values of the Temperature of Combustion, Illuminance, Duration of Combustion, and the Groups Resulting from the Least Significant Difference (LSD) Analysis during Combustion with or without Flame and During Afterglow

Factor		CWF		CWOF		CDA		CT (sn)	
		IV (lüx)	TV (°C)	IV (lüx)	TV (°C)	IV (lüx)	TV (°C)	CTV (sn)	CTT (sn)
Types of process	Yearly	301 a	490 b	300 b	582 b	303 a	362 a	337 b	569 b
	Control	300 b	502 a	301 a	628 a	302 b	341 a	379 a	728 a
	Ort.	301	496	301	605	303	352	358	649
	S_x	0.71	8.49	0.71	32.53	0.71	14.85	29.70	112.43
	LSD	0.9291	8.8182	1.0911	8.294	0.8531	22.258	7.1643	46.305
Types of Varnish	Water-Based	301 a	496 ab	301 a	604 ab	303 a	350 a	362 a	656 a
	Synthetic	300 a	486 b	300 a	598 b	303 a	341 a	355 a	672 a
	Control	300 a	506 a	300 a	613 a	302 b	364 a	357 a	618 a
	Ort.	300	496	300	605	303	352	358	648.67
	S_x	0.58	10	0.58	7.55	0.58	11.59	3.61	27.74
	LSD	1.1379	10.8	1.3363	10.158	1.0449	27.26	8.7744	56.712
Materials of Impregnate	Tanalith-E	300 a	489 ab	301 b	592 b	303 a	336 b	360 a	656 ab
	Wolmanit-CB	301 a	504 a	302 a	616 a	303 a	367 a	354 a	615 b
	Control	300 a	495 b	300 b	607 a	302 a	351 ab	360 a	676 a
	Ort.	300	496	301	605	303	351	358	649
	S_x	0.58	7.55	1	12.12	0.58	15.50	3.45	31.10
	LSD	1.1379	10.8	1.3363	10.158	1.0449	27.26	8.7744	56.712

CWF: combustion with flame, CWOF: combustion without flame, CDA: combustion during afterglow, CT: time of combustion, CTV: value of time to collapse, CTT: total time of combustion, WL: weight loss, IV: values of illuminance, TV: values of temperature

Weight Loss of Wood Samples in Combustion

The differences in weight loss and weathering changes were determined as significant at a level of 1% (Table 3).

Table 3. Results of the Analysis of Variance for Weight Loss of Wood Samples in Combustion

Source of Variance		F.D.	S.S.	S.M.	F.V.
Weight Loss (WL) (%)	pt	1	12.99	12.99	17.99*
	vt	2	2.42	1.21	1.68
	im	2	3.58	1.79	2.47
	pt*im	2	1.29	0.64	0.89
	pt*vt	2	18.46	9.23	12.77*
	im*vt	4	6.37	1.59	2.20
	pt*im*vt	4	6.91	1.73	2.39
	Error	36	26.01	0.72	
	Total	53	78.03		

The mean weathering effect on weight loss ratios of chestnut wood samples was the lowest for the control group (84.65%), lower for the Wolmanit-CB group (83.82%) than the Tanalith-E group (84.20%), and lower for the use of synthetic varnish (83.98%) than for the use of water-based varnish (84.46%) (Table 4, Fig. 1, Fig. 2).

Weight loss of the impregnated chestnut wood samples was the lowest for control samples with respect to the weathering changes. The weight loss was lower for samples that were impregnated with Wolmanit-CB than those that were impregnated with Tanalith-E. Weight loss was lower using synthetic varnish than water-based varnish.

The weight loss ratio was reported to be 92.06% (Temiz *et al.* 2008) and 94% for Scots pine control samples in another study (Atılgan and Peker 2012). The weight loss

ratio of the chestnut wood samples was 84.65% in the present study. This value was higher than those reported for Scots pine samples, which was likely a result of the presence of extractive materials in chestnut, Calabrian pine, and Scots pine wood samples.

Table 4. Mean Values and Least Significant Difference (LSD) Analysis of Weight Loss

Factor		Weight Loss (%)
Type of process	Yearly	83.67 b
	Control	84.65 a
	Ort.	84.16
	S_x	0.70
	LSD	0.4692
Type of Varnish	Water-Based	84.46 a
	Synthetic	83.99 a
	Control	84.02 a
	Ort.	84.16
	S_x	0.26
	LSD	0.5746
Impregnation Material	Tanalith-E	84.20 ab
	Wolmanit-CB	83.82 a
	Control	84.45 a
	Ort.	84.16
	S_x	0.32
	LSD	0.5746

Figures 1 and 2 display the weight loss due to the combustion of the impregnated wood samples as a function of weathering changes, the type of impregnating material used, and the type of varnish employed.

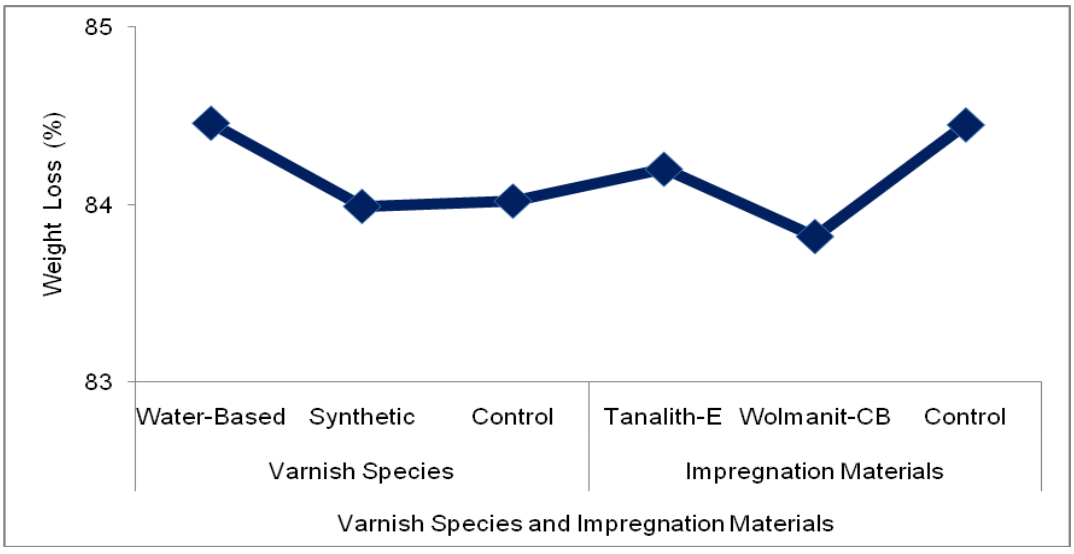

Fig. 1. Weight loss of wood impregnated and varnished with different materials during combustion experimentation

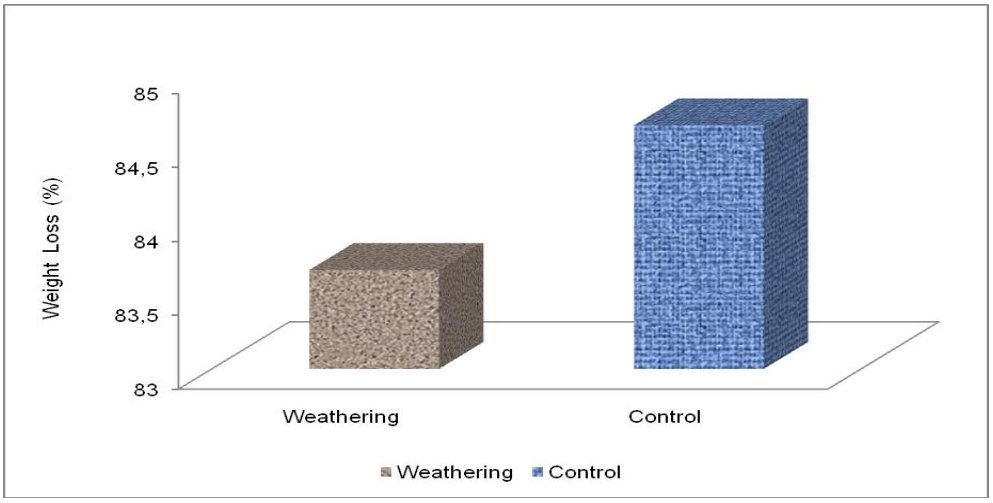

Fig. 2. Weight loss during combustion experiments

Values of Wood Samples in Gas Analysis

The results of the analysis of variance of the flue gas content of chestnut wood during combustion with or without flames and during afterglow are presented in Table 5. The difference in the O_2 content of the flue gas released during the combustion of the impregnated chestnut wood samples with or without flame and during afterglow was determined to be significant at 1% significant level for the weathering effects, during combustion with flame at 1% significant level for the type of varnish, and during combustion without flame and during afterglow at 5% significant level for the type of impregnating material. The differences in the CO_2 content of the flue gas released during combustion of the impregnated cedar wood samples with flame was determined to be significant at 1% significant level for the weathering effects, during combustion without flame at 1% significant level for the type of impregnating material, during afterglow at 1% significant level for the type of varnish, and during combustion without flame and during afterglow at 5% significant level for the type of varnish. The differences in the CO content of the flue gas released during combustion with or without flame and during afterglow was determined to be significant at a threshold of 1% for the weathering effects for the effect of the type of impregnating materials (Table 5).

The mean values and the results of the LSD test were calculated as shown in Table 6. During combustion with flame, the highest mean O_2 content, 12.94%, occurred in yearly samples. The highest mean CO_2 content, 8.91%, was found in control samples, and the highest mean CO content of 17.883 ppm was in the control samples. During combustion without flame, the highest mean O_2 content was 1.29% in control samples, the highest mean CO_2 content was 19.41% in control samples, and the highest mean CO content was 31.843 ppm in yearly samples. During afterglow, the highest mean O_2 content during was 10.17% in control samples, the highest mean CO_2 content was 11.50% in yearly samples, and the highest mean CO content was 17.890 ppm in control samples (Fig. 3). The results of the flue gas analysis with respect to the type of impregnating material indicated that the CO_2 and CO contents of the samples impregnated using Wolmanit-CB were lower than those impregnated with Tanalith-E, whereas the O_2 content was higher during combustion with or without flame and during afterglow.

Table 5. Results of the Analysis of Variance of the Flue Gas during Combustion with or without Heat Source and that of Afterglow

Source of Variance		O_2 (%)				CO_2 (%)				CO (ppm)			
		F.D.	S.S.	S.M.	F.V.	F.D.	S.S.	S.M.	F.V.	F.D.	S.S.	S.M.	F.V.
Combustion With Flame	pt	1	3041	608	214*	1	6390	1278	69.28*	1	4514394323	902878865	142.81*
	im	2	41	21	7.22*	2	266	133	7.21*	2	56867562	28433781	4.50**
	vt	2	0.02	0.08	0,001	2	100	50	2.71	2	10383435	5191717	0.82
	pt *im	2	158	159	5.56*	2	669	67	3.62*	2	157650034	15765003	2.49*
	pt *vt	2	102	102	3.57*	2	498	50	2.7*	2	473245462	47324546	7.49*
	im*vt*	4	23	23	2.02	4	246	61	3.33**	4	15494587	3873647	0.61
	pt *im*vt	4	102	102	1.79**	4	1177	59	3.19*	4	246246652	12312333	1.95**
	Error	36	308	2.85		36	1992	18.45		36	682805218	6322271	
	Total	53	3775			53	11337			53	6157087272		
Combustion Without Flame	pt	1	6300	1260	700*	1	5809	1162	679*	1	10083192774	2016638555	456.06*
	im	2	16	8.04	4.46**	2	15.46	7.73	4.52**	2	47791251	23895625	5.40*
	vt	2	5.69	2.85	1.58	2	5.16	2.58	1.51	2	9780507	4890253	1.11
	pt *im	2	56	5.63	3.13**	2	52.80	5.28	3.09*	2	66949444	6694944	1.51
	pt *vt	2	7.4	0.74	0.14	2	8.09	0.81	0.47	2	39213088	3921309	0.89
	im*vt*	4	24	5.97	3.32**	4	22.55	5.56	3.25**	4	26459109	6614777	1.50
	pt *im*vt	4	80	4	2.22*	4	77.55	3.88	2.27*	4	271843189	13592159	3.07*
	Error	36	194	1.8		36	185	1.71		36	477562148	4421872	
	Total	53				53				53	11022791508		
Combustion During Afterglow	pt	1	855	171	50.07*	1	881	176	55.11*	1	1794795252	358959050	45.62*
	im	2	29.89	14.95	4.38**	2	24.14	12.07	3.77**	2	106583749	53291874	6.77*
	vt	2	25.85	12.93	3.79**	2	31.35	15.67	4.90*	2	33665985	16832993	2.14
	pt *im	2	60.92	6.09	1.78	2	51.71	5.17	1.62	2	183956061	18395606	2.34**
	pt *vt	2	122.16	12.22	3.58**	2	105.62	10.56	3.30*	2	170747276	17074728	2.17**
	im*vt*	4	75.46	18.86	5.52*	4	90.32	22.58	7.06*	4	295008181	73752045	9.37*
	pt *im*vt	4	214.89	10.75	3.15*	4	190	9.50	2.97*	4	460852671	23042634	2.93*
	Error	36	368.76	3.42		36	1374	3.19		36	849743891	7867999	
	Total	53	1753			53	346			53	3895353066		

The O_2 content of the flue gas from combustion was higher for the outdoor samples during combustion with or without flame and during afterglow than for the control samples; however, their CO content was lower. During combustion with or without flame and during afterglow, the CO_2 and CO contents of the samples impregnated with Wolmanit-CB were lower and their O_2 content was higher than those that were impregnated with Tanalith-E. During combustion with flame, the CO_2 content of the samples that were treated with synthetic varnish was higher and their CO and O_2 contents were lower than samples that were treated with water-based varnish. Additionally, during combustion without flame, the O_2 and CO_2 contents were higher whereas the CO content was lower, and during afterglow, the O_2 content was higher, while the O_2 and CO contents were lower.

Different types of varnish on chestnut wood during combustion with or without flame and during afterglow revealed that the CO_2 content of the samples with synthetic varnish was higher and the O_2 and CO contents were lower than those that were treated with water-based varnish during combustion with flame. The O_2 and CO_2 contents were higher and the CO content was lower during combustion without flame, and the O_2 content was higher, while the O_2 and CO contents were lower during afterglow (Table 6).

In the literature, according to gas analysis results obtained from LVL specimens of laminated wood materials produced from yellow pine wood, since impregnated specimens burned less compared to control specimen in combustion with flame source and without flame source, the decrease in the O_2 amount was also lower compared to control specimen. Due to the fact that self-combustion continues in the control specimen after the flame source was removed from the flame chimney, CO amount was increased

(Özen *et al.* 2000). The data we obtained as a result of combustion test show similarity with this article.

In a study, the O_2 content of flue gas from Scots pine wood control samples was reported as: 9.35% CWF, 7.46% CWOF, and 10.32% CDA; the CO_2 content was determined as 4.98% CWF, 6.61% CWOF, and 3.93% CDA; and the CO content was determined as 28.49 ppm CWF, 59.33 ppm CWOF, and 173.8 ppm CDA (Atar *et al.* 2010). In the present study, the O_2 content was 12.56% CWF, 0.84% CWOF, and 10.17% CDA; the CO_2 content was 8.91% CWF, 18.95% CWOF, and 10.27% CDA; and the CO content was 17.883 ppm CWF, 30.431 ppm CWOF, and 17.890 ppm CDA. These values are thought to be the result of the presence of extractive material in the composition of chestnut and Scots pine wood samples.

Table 6. Mean Values of the Flue Gas Composition and the Groups Resulting from the Least Significant Difference (LSD) Analysis during Combustion with or without Heat Source and that of Afterglow

Factor		*Combustion With Flame*			*Combustion Without Flame*			*Combustion During Afterglow*		
		O_2 (%)	CO_2 (%)	CO (ppm)	O_2 (%)	CO_2 (%)	CO (ppm)	O_2 (%)	CO_2 (%)	CO (ppm)
Types of process	Annual	12.94 a	8.46 a	14354 b	0.84 b	19.41 a	31844 a	8.99 a	11.50 a	15760 b
	Control	12.56 b	8.91 a	17883 a	1.29 a	18.95 b	30431 b	10.17a	10.27 b	17890 a
	Ort,	12.75	8.69	16119	1.07	19.18	31138	9.58	10.89	16825
	S_x	0.27	0.32	2495.38	0.32	0.33	999.14	0.83	0.87	1506.14
	LSD	1.1647	1.0908	1604	0.3166	0.3208	534.32	1.2599	1.2199	1885.9
Materials of Impregnate	Wolmanit-CB	14.16 a	7.68 b	15295 a	1.48 a	18.77 b	31154 a	10.69 a	9.85 b	15156 b
	Tanalith-E	12.73 b	8.85ab	16338 a	0.74 b	19.48 a	31363 a	8.79 b	11.67 a	18942 a
	Control	11.35 b	9.53 a	16722 a	0.98 b	19.22 a	30894 a	9.27ab	11.14 ab	16378 b
	Ort,	12.75	8.69	16118	1.07	19.16	31137	9.58	10.89	16825
	S_x	1.41	0.94	738.43	0.38	0.36	234.96	0.99	0.94	1932.23
	LSD	1.4265	1.336	1964.5	0.3879	0.3929	654.41	1.543	1.4941	2309.8
Types of Varnish	Synthetic	11.79 b	9.87 a	18129 a	0.76 b	19.52 a	31517 a	10.30a	10.13 b	16449 a
	Water-Based	12.96ab	8.66ab	15225 b	1.12ab	19.05 b	31533 a	9.76ab	10.72 ab	16639 a
	Control	13.49 a	7.53 b	15001 b	1.32 a	18.96 b	30362 b	8.69 b	11.81 a	17388 a
	Ort,	12.75	8.69	16118	1.07	19.18	31137	9.58	10.89	16825
	S_x	0.87	1.17	1744.89	0.28	0.30	672	0.65	0.85	496.46
	LSD	1.4265	1.336	1964.5	0.3878	0.3929	654.41	1.543	1.4941	2309.8

The interaction effects among weathering, the type of impregnating material, and the varnish type are reported in Table 7. The total duration of combustion and the temperature of combustion during afterglow were negatively and significantly correlated (r=-0.80*), as shown in Table 5. The total duration of combustion and the time to collapse were positively and significantly correlated (r=0.79*). The NO content and the total duration of combustion during combustion without flame were positively and significantly correlated (r=0.75*). The CO_2 contents and the O_2 contents during combustion with the flame were negatively and significantly correlated (r=-0.79*). The CO_2 contents and the O_2 contents during combustion without flame and during afterglow were both negatively and significantly correlated (r=-0.99*). The CO_2 content and the CO content during combustion with flame were positively and significantly correlated (r=0.75*). The NO and the CO contents during combustion with flame were negatively and significantly correlated (r=-0.79*).

Table 7. Multiple Correlation Analysis of the Weight Loss Ratios, Temperature Values, Illuminance, and of the Concentrations of Liberated Oxygen (O_2), Carbon Dioxide (CO_2), and Carbon Monoxide (CO) during Combustion with or without Heat Source and that of Afterglow

	A^1	B^2	C^3	D^4	E^5	F^6	G^7	H^8	I^9	K^{10}	L^{11}	M^{12}	N^{13}	O^{14}	P^{15}	R^{16}	S^{17}	T^{18}
A^1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B^2	0.74*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C^3	0.01	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D^4	0.19	-0.19	-0.42*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E^5	0.25	0.26	-0.26	0.56*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F^6	-0.23	-0.37*	-0.47*	0.68*	0.65*	-	-	-	-	-	-	-	-	-	-	-	-	-
G^7	0.27**	0.55*	-0.55*	0.10	0.35**	0.02	-	-	-	-	-	-	-	-	-	-	-	-
H^8	0.15	0.36*	-0.80*	0.28**	0.34**	0.34**	0.79*	-	-	-	-	-	-	-	-	-	-	-
I^9	0.28**	0.28**	0.25	-0.52*	0.22	0.21	0.50*	0.71*	-	-	-	-	-	-	-	-	-	-
K^{10}	0.33**	0.23	0.40*	0.09	0.25	-0.15	-0.12	-0.32**	-0.40*	-	-	-	-	-	-	-	-	-
L^{11}	0.52*	0.42*	-0.07	0.40*	0.56*	0.12	0.37*	0.16	0.33**	0.06	-	-	-	-	-	-	-	-
M^{12}	0.16	0.18	-0.61*	0.48*	0.58*	0.51*	0.49*	0.63*	0.44*	-0.15	0.37*	-	-	-	-	-	-	-
N^{13}	-0.24	-0.16	-0.23	-0.13	-0.25	0.13	0.13	0.19	0.15	-0.79*	-0.21	0.16	-	-	-	-	-	-
O^{14}	-0.49*	-0.40*	0.10	-0.46*	-0.66*	-0.20	-0.41*	-0.19	-0.34**	-0.09	-0.99*	-0.41*	0.24	-	-	-	-	-
P^{15}	-0.15	-0.19	0.62*	-0.48*	-0.57*	-0.49*	-0.51*	-0.64*	-0.43*	0.15	-0.36*	-0.99*	-0.16	0.39*	-	-	-	-
R^{16}	0.06	0.23	-0.42*	-0.09	-0.0001	0.17	0.35**	0.50*	0.37*	-0.59*	-0.05	0.40*	0.75*	0.08	-0.41*	-	-	-
S^{17}	-0.41*	-0.45*	0.30**	-0.69	-0.17	0.20	-0.58*	-0.42*	-0.39*	0.13	-0.65*	-0.40*	-0.05	0.59*	0.39*	-0.31**	-	-
T^{18}	-0.22	-0.02	0.10	-0.45*	-0.19	-0.21	-0.10	-0.13	-0.04	-0.08	-0.14	-0.62*	-0.12	0.16	0.62*	-0.19	0.11	-

A^1: temperature with flame, B^2: temperature without flame, C^3: temperature aftergrow, D^4: illuminance with flame, E^5: illuminance without flame, F^6: illuminance aftergrow, G^7: time to collapse, H^8: total time of combustion, I^9: weight loss, K^{10}: amount of O_2 of combustion with flame, L^{11}: amount of O_2 of combustion without flame, M^{12}: amount of O_2 of combustion during afterglow, N^{13}: amount of CO_2 of combustion with flame, O^{14}: amount of CO_2 of combustion without flame, P^{15}: amount of CO_2 of combustion during afterglow, R^{16}: amount of CO of combustion with flame, S^{17}: amount of CO of combustion without flame, T^{18}: amount of CO of combustion without flame

CONCLUSIONS

1. Based on the findings of this work, wooden materials to be used in places with fire hazard should not be coated with varnish after impregnation.
2. The greatest advantage that wood provides in the event of fire is the fact that it burns slowly and forewarns about collapse, thus minimizing the loss of lives. The samples that had been exposed outdoors for a year that were impregnated using Wolmanit-CB and treated with synthetic varnish were determined to be safer to employ in areas with high fire risk.
3. Weight loss of the samples left outdoors was higher for those that were impregnated with Tanalith-E and treated with water-based varnish.

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