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INFLUENCES OF SEASONAL ALTERATIONS ON THE BURNING CHARACTERISTICS OF IMPREGNATED AND SURFACE TREATED CHESTNUT (*CASTANEA SATIVA* MILL) WOOD

S. Sadiye Yasar
Gumushane University, Gumushane Vocational High School
Department of Desing
Gumushane, Turkey

Muhammed Said Fidan
Gumushane University, Institute of Natural Applied Science
Department of Forestry and Evironment Sciences
Gumushane, Turkey

Mehmet Yasar
Gumushane University, Gumushane Vocational High School
Department of Desing
Gumushane, Turkey

Musa Atar
Gazi University, Faculty of Technology, Department of Wood Products
Industrial Engineering
Ankara, Turkey

Elif Alkan
Gumushane Uniersity, Institute of Natural Applied Science
Department of Forestry And Evironment Sciences
Gumushane, Turkey

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ABSTRACT

Wood material is generally preferred due to its resilience against earthquakes, aesthetic properties, and its warmth as well as being natural. One of the major problems of employing this natural and breathable product is its ease of combustibility. Despite this adverse characteristic, its high resistance against burning and its ability to maintain its weight bearing characteristics until the very end does not lead to sudden collapses as is seen in steel and concrete systems. Treating wood with impregnating materials in order to improve its resistance against burning is an improved safety measure for the prevention of ignition.

This study investigate seasonal effects on the ignition characteristics of chestnut wood samples impregnated using either Tanalith-E or Wolmanit-CB as detailed in ASTM–D 1413–76 and surface-treated using water-based or synthetic varnish as detailed in ASTM-D 3023- 88.

The temperature of burning process was the highest in the investigated samples, in those impregnated with Wolmanit-CB and those that were treated with water-based varnish. The results of the study indicated that weight loss was lower during winter (84.59 %), for samples that were impregnated using Wolmanit-CB (84.46 %) and in those that were treated with water-based varnish (84.18 %). On the other hand, the O_2 content was determined to be the highest and the CO content the lowest in winter samples that were impregnated using Wolmanit-CB and treated with synthetic varnish.

KEYWORDS: Chestnut, wood, impregnated, varnish, burning, seasonal change.

INTRODUCTION

Wood materials have been utilized by humans since prehistoric times. Wood material, an organic living substance, has found itself in a wide area of use that continues to widen over time. Reasons for this widespread use are its high resistance despite its lightness, ease of workability and its ability to hold nails and screws (Aslan 1998). Wood is widely used as a building material in many regions (Grexa 2000). Wood is a combustible supplies (Breyer 1993).

When employed outdoors, chemical changes occurring in the major constituents of wood, cellulose, hemicellulose and lignins, lead to changes of color, loss of luster, increased roughness and formation of cracks on the surface (Hon and Shiraishi 2001). Because of this chemical decay, it is of utmost importance to extend the use of wood material through impregnation using water repellant, biotic and abiotic chemicals and varnishing 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).

Although it offers protection for wood material against adverse weather conditions, varnish is comprised of chemical compounds that are extremely flammable and ignitable, facilitating and speeding the burning of wood (Şanivar 1997). An earlier study on calabrian pine reported that the resistance of the wood against burning was increased upon impregnation with an aqueous solution of boric acid (BA) and sodium perborate (SP) and that the boron salts reduced the intensity of smoke during burning (Yalınkılıç 1996).

Wood examples treated with boron compounds reduced the weight losses and were effective as a fire retardant (Baysal 1994; Yalınkılıc 1996; Temiz 2000; Colak et al. 2002). Borax and boric acid are most widespread boron compounds which have found many execution areas in the wood preservation industry in an attempt to get the benefit of their fire retardancy (Le Van and Tran 1990; Baysal 2002).

MATERIAL AND METHODS

Material

The wood material used in the study was randomly procured from Anatolian chestnut wood. Care was taken to sample from normally and regularly grown pieces of wood material that were resin-free, regular-fibred, and knot-free. The randomly selected timber were acclimatized at a temperature of 20±2°C and relative humidity of 65±3 % until they achieved constant moisture content of 12 % prior to coarse cutting.

Methods

Preparation of the test samples

The experimental samples were regularly cut in sizes of 13x13x76 mm (radial x tangent x length). A total of 3240 test samples were prepared from Anatolian chestnut wood to investigate the effect of 2 different impregnating materials, 2 different types of varnish, 4 seasons and for the investigation of samples with 3 groups, with 24 samples in each group (5x2x2x24x3). The test samples were dried at 20±2°C and a relative humidity of 65±5 % until they reached constant weight prior to any treatment application and they were weighed to a precision of 0.01 g.

Impregnation

The vacuum-pressure method was employed for impregnation as detailed in ASTM-D 1413-76. The impregnated materials were left in an air-circulated room for 15-20 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 moisture content of 12 %.

Determination of the extent of retention

The extent of retention of the impregnating material in the test samples was calculated by making use of the values prior to and post impregnation using the following equations (TS 5724, 1988).

$$R = \left[\frac{G.C}{V}\right] \times 10^3 \qquad (kg.m^{-3})$$

where: $G = T_2 - T_1$,
T_1 - sample weight prior to impregnation (g),
T_2 - sample weight post impregnation (g),
V - sample volume (cm^3),
C - concentration of the solution (%).

The mean retention of the samples used in the experiments along with the relevant statistical parameters are provided in Tab. 1.

Tab. 1: Mean retention of the test samples used in the experiments.

Retention ($kg.m^{-3}$)	
Tanalith-E	**Wolmanit-CB**
2.47	2.90

Varnish application

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 0.01 g. 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.

Outdoor exposure

Varnished test samples were left to remain outdoors, as their seasonal groups dictated, to be exposed to the elements. The samples were placed on the test stand at an angle of 45° facing south. The study investigated the effect of outdoor elements on the ignition characteristics of wood material. Therefore, test samples were periodically left outdoors along with their investigated samples; the summer group was analyzed in June, the fall group in September, the winter group in December and the spring group in March.

Combustion tests and flue gas analysis

The impregnated/non-impregnated and varnished/unvarnished samples were removed from the outdoor environment at the end of their periodic exposure and the ignition characteristics of the samples were determined using the apparatus as detailed in the ASTM-E 160–50 1975 standard (Fig. 1). 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 (AKY). Then the source was extinguished to allow burning without flame (KKY) and the afterglow (KHY) stages.

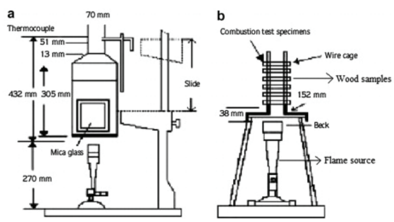

Fig. 1: Fire test apparatus (Temiz et al. 2008).

The duration of burning with flame (s), the duration of burning without flame (s) and the duration of burning during afterglow (s) and the weight loss ratio (%) of the samples were determined.

The relative amounts of oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO) and nitrogen monoxide (NO) gases released during combustion with or without heat source as well as during afterglow of the samples left outdoors seasonally or yearly were determined using the apparatus detailed in Fig. 1.

Statistical evaluation of the data

The temperature of burning process, the illuminance, the duration of burning, the weight loss and the results of the gas analyses of the samples measured in triplicate were used to conduct an analysis of variance employing randomized block factorial experimental design using SAS software. The mean values were compared using the least significant difference (LSD) test. Finally, multiple correlation analysis was carried out in order to investigate the relationship between groups (SAS 1989).

RESULTS AND DISCUSSION

The extent of retention of the samples impregnated with the given materials were determined as detailed in Tab. 1.

The results of the analysis of variance of the seasonal effects on the weight loss and the duration of burning process of impregnated and surface treated chestnut wood as well as of the type of impregnating material and the type of varnish on the temperature of burning and the illuminance of the chestnut wood during burning with (CWF) or without flames (CWOF) and during afterglow (CDA) are presented in Tab. 2. The mean values, the standard deviations and the results of the LSD test are given in Tab. 3.

Tab. 2: Results of the analysis of variance for the temperature of burning, illuminance, the duration of burning and weight loss ratios.

Source of Varience	Values of illuminance (IV) (lüx)				Values of temperature (TV) (°C)			
	F.D.	S.S.	S.M.	F.V.	F.D.	S.S.	S.M.	F.V.
Burning with flame (BWF)								
Change of seasonal (sc)	4	448607.07	112151.77	631.88*	4	63087.38	15771.84	48.39*
Types of varnish (vt)	2	952.58	476.29	2.68	2	3052.93	1526.47	4.68*
Materials of impregnate (im)	2	16.18	8.09	0.05*	2	1484.93	742.47	2.28*
sc*vt	8	2042.31	255.29	1.44	8	5570.18	696.69	2.14**
sc*im	8	441.60	55.20	0.31	8	7125.51	890.69	2.79*
vt*im	4	2291.51	572.88	3.23**	4	5070.53	1267.63	3.89*
sc* vt*im	16	5342.49	333.91	1.88**	16	20997.47	1312.34	4.03*
Error	90	15974.00	177.49		90	29334.00	325.93	
Total	134	475667.73			134	135722.93		
Burning without flame (BWOF)								
Change of seasonal (sc)	4	158728.04	39682.01	53.01*	4	158728.04	39682.01	53.01*
Types of varnish (vt)	2	3303.75	1651.87	2.21	2	3303.75	1651.87	2.21
Materials of impregnate (im)	2	7692.64	3846.32	5.14*	2	7692.64	3846.32	5.14*
sc*vt	8	10308.84	1288.61	1.72	8	10308.84	1288.61	1.72
sc*im	8	20699.29	2587.41	3.46*	8	20699.29	2587.41	3.46*
vt*im	4	7436.30	1859.07	2.48**	4	7436.30	1859.07	2.48**
sc* vt*im	16	74020.89	4626.31	6.18*	16	74020.89	4626.31	6.18*
Error	90	67375.33	748.62		90	67375.33	748.62	
Total	134	349565.05			134	349565.05		
Burning during afterglow (BDA)								
Change of seasonal (sc)	4	105847.21	26461.80	27.34*	4	105847.21	26461.80	27.34*
Types of varnish (vt)	2	2679.13	1339.56	1.38	2	2679.13	1339.56	1.38
Materials of impregnate (im)	2	16529.88	8264.94	8.54*	2	16529.88	8264.94	8.54*
sc*vt	8	25889.76	3236.22	3.34*	8	25889.76	3236.22	3.34*
sc*im	8	40317.67	5039.71	5.21*	8	40317.67	5039.71	5.21*
vt*im	4	18498.39	4624.60	4.78*	4	18498.39	4624.60	4.78*
sc* vt*im	16	24133.62	1508.35	1.56	16	24133.62	1508.35	1.56
Error	90	87110.67	967.90		90	87110.67	967.90	
Total	134	321006.33			134	321006.33		
Time of burning (CT)(sn)								
Value of time to collapse (CTV)					*Total time of burning (BTT)*			
Change of seasonal (sc)	4	5616576.64	1404144.16	15.69*	4	482338.27	120584.57	20.94*
Types of varnish (vt)	2	555541.51	277770.76	3.10*	2	64760.13	32380.07	5.62*
Materials of impregnate (im)	2	663249.24	331624.62	3.71*	2	137472.31	68736.16	11.93*
sc*vt	8	2452197.45	306524.68	3.43*	8	232778.98	29097.37	5.05*

sc*im	8	2353487.94	294185.99	3.29*	8	226974.58	28371.82	4.93*
vt*im	4	1163587.11	290896.78	3.25**	4	312774.36	78193.59	13.58*
sc* vt*im	16	4972533.70	310783.36	3.47*	16	426504.98	26656.56	4.63*
Error	90	8052871.33	89476.35		90	518373.33	5759.70	
Total	134	25830044.93			134	2401976.93		
Weight loss (WL) (%)								
Source of varience	F.D.	S.S.	S.M.	F.V.				
Change of seasonal (sc)	4	35.96	8.99	9.24*				
Types of varnish (vt)	2	7.79	3.89	4**				
Materials of impregnate (im)	2	16.50	8.25	8.48*				
sc*vt	8	35.32	4.41	4.54*				
sc*im	8	26.01	3.25	3.34*				
vt*im	4	37.43	9.36	9.62*				
sc* vt*im	16	36.72	2.30	2.36*				
Error	90	87.56	0.97					
Total	134	283.29						

F.D.: Degrees of freedom, S.S.: Sum of squares, S.M.: Mean of squares, F.V.: F Value.

Tab. 3: Mean values of the temperature of burning, illuminance, duration of burning, and the weight loss ratios and the groups resulting from the least significant difference (LSD) analysis.

Faktor	WL (%)	BWF		BWOF		BDA		BT	
		IV (lüx)	TV (°C)	IV (lüx)	TV (°C)	IV (lüx)	TV (°C)	TIV (sn)	VTC (sn)
Change of seasonal (SC)									
Winter	84.59^{a}	342^{c}	443^{c}	348^{c}	545^{c}	351^{c}	339^{a}	352^{b}	607^{b}
Spring	84.44^{a}	438^{b}	482^{b}	400^{b}	529^{d}	400^{b}	299^{b}	378^{a}	700^{a}
Summer	83.87^{b}	452^{a}	501^{a}	453^{a}	582^{b}	449^{a}	276 c	447^{b}	740^{a}
Fall	83.35^{b}	299^{d}	476^{b}	296^{d}	568^{b}	299^{d}	342^{a}	332^{b}	600^{b}
Investigated	84.65^{a}	300^{d}	502^{a}	301^{d}	628^{a}	302^{d}	346^{a}	379^{b}	728^{b}
Ort.	84.18	366	481	360	570	360	320	378	675
Sx	0.56	74.16	24.04	67.03	38.14	64.59	31.25	43.45	66.91
LSD	0.5333	10.672	9.7617	7.97	14.794	7.2035	16.822	161.74	41.036
Types of varnish (VT)									
Water-based	84.18^{ab}	366^{ab}	483^{a}	361^{ab}	575^{a}	362^{a}	320^{a}	568^{a}	664^{b}
Synthetic	83.91^{b}	362^{b}	474^{b}	355^{b}	563^{a}	356^{b}	315^{a}	430^{b}	706^{a}
Investigated	84.5^{a}	371^{a}	486^{a}	363^{a}	573^{a}	362^{ab}	326^{a}	435^{b}	656^{b}
Ort.	84.20	366	581	360	570	360	320	478	675
Sx	0.30	4.51	6.24	4.16	6.43	3.46	5.51	78.27	26.86
LSD	0.4131	8.2662	7.5614	6.1735	11.459	5.5798	13.03	125.28	31.786
Materials of impregnate (IM)									
Tanalith-E	83.70^{b}	362^{b}	476^{b}	362^{a}	573^{a}	361^{a}	331^{a}	424^{b}	641^{b}
Wolmanit-CB	84.46^{a}	363^{b}	483^{a}	360^{a}	578^{a}	360^{a}	325^{a}	433^{b}	667^{b}
Investigated	84.43^{a}	374^{a}	484^{a}	358 a	560^{b}	360^{a}	305^{b}	577^{a}	718^{b}
Ort.	84.20	366	481	360	570	360	320	478	675
Sx	0.43	6.66	4.36	2	9.29	0.58	13.61	85.85	39.17
LSD	0.4131	8.2662	7.5614	6.1735	11.459	5.5798	13.03	125.28	31.786

BWF; Burning with flame, BWOF; Burning without flame, BDA; Burning during afterglow, TIB; Time of burning, VTC; Value of time to collapse, WL; *WeightlLoss*, IV; Values of illuminance, TV; Values of temperature.

The differences in the weight loss percentage were determined to be significant for the effect of seasons and the type of impregnating material employed. The temperature of burning and illuminance during burning with or without flame and during afterglow were determined to be significant at a threshold of 1 % for the effect of seasons and the type of impregnating material employed. The differences in time to collapse and total duration of burning were determined to be significant at a threshold of 1 % for the seasonal changes, the type of impregnating material and varnish type parameters. The differences in weight loss were determined to be significant at a threshold of 5 % for the type of varnish employed in the conducted analysis of variance (Tab. 2).

The maximum illuminances of the impregnated and surface treated chestnut wood samples were 452 lux (CWF), 453 lux (CWOF) and 449 lux (CDA) for the seasonal effect with the summer samples having the highest values; 362 lux (CWF), 362 lux (CWOF) and 361 lux (CDA) or 363 lux (CWF), 360 lux (CWOF) and 360 lux (CDA) for the employment of Tanalith-E or Wolmanit-CB as the impregnating material with the values being similar for the application of two different materials; and 366 lux (CWF), 361 lux (CWOF) and 362 lux (CDA) or 362 lux (CWF), 355 lux (CWOF) and 356 lux (CDA) for the water-based or synthetic varnish application (water-based varnish application resulting in slightly higher but very similar luminosity values) (Tab. 3).

The maximum mean temperatures of burning were 502°C (CWF), 628°C (CWOF) and 346°C (CDA) for the seasonal effect, with the investigated values being the highest; 483°C (CWF), 575°C (CWOF) and 320°C (CDA) for the effect of the type of varnish with the employment of water-based varnish yielding higher values (in comparison to that of synthetic varnish application; 474°C (CWF), 563°C (CWOF) and 315°C (CDA)); and 483°C (CWF), 578°C (CWOF) and 325°C (CDA) for the effect of the impregnating material with the employment of Wolmanit-CB yielding higher values (in comparison to that of Tanalith-E; 476°C (CWF), 573°C (CWOF) and 331°C (CDA)) (Tab. 3).

The longest time to collapse (CTV) was 378s for the spring samples while the longest total time of burning (CTT) was 740 s for the summer samples with respect to the seasonal effect; 433 s (CTV) and 667 s (CTT) for the effect of the employment of Wolmanit-CB, which was higher than those for the effect of Tanalith-E application (424 s (CTV) and 641 s (CTT)); and 568 s (CTV) and 664 s (CTT or 430 s (CTV) and 706 s (CTT) for the water-based or synthetic varnish application, respectively, indicating nearly similar durations (Tab. 3).

The mean seasonal effect on weight loss of the samples was the lowest for the winter group (84.59 %), higher for the Wolmanit-CB impregnated group (84.46 %) than for the Tanalith-E group (83.70 %) and lower for the use of synthetic varnish (84.18 %) than that for the use of water-based varnish (89.12 %) (Tab. 3).

The results of the analysis indicated that the highest mean weight loss occurred in the investigated samples impregnated with Tanalith-E (69.71 %) whereas the highest weight loss was determined for the control samples impregnated with borax (43.04 %). This was due to the high retention nature of borax as an impregnating chemical (Uysal et al. 2011).

Figs. 2 and 3 display the weight loss due to the burning of the impregnated wood samples as a function of seasonal changes, the type of impregnating material being used and the type of varnish being employed.

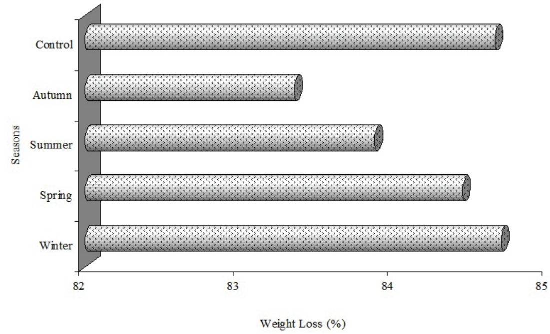

Fig. 2: Seasonal variations in weight loss during burning.

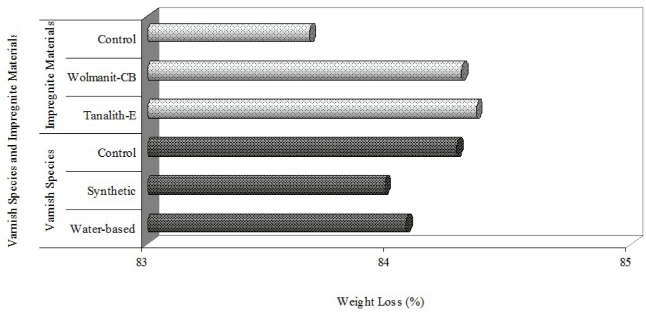

Fig. 3: Weight loss during burning with respect to differences in type of impregnating material or varnish used.

The lowest weight loss ratio was determined for the winter samples and the highest for the winter samples; it was lower for the samples that were impregnated with Tanalith-E rather than Wolmanit-CB and for those treated using water-based varnish rather than synthetic varnish as shown in Figs. 2 and 3.

The results of the analysis of variance of the flue gas content during burning with or without flames and during afterglow are presented in Tab. 4. The mean values and the results of the least significant difference (LSD) test were calculated as given in Tab. 5.

Tab. 4: Results of the analysis of variance of the flue gas released during burning.

Source of varience	O_2 (%)				CO (ppm)				NO (ppm)				CO_2 (%)			
	F.D.	S.S.	S.M.	F.V.	F.D.	S.S.	S.M.	F.V.	F.D.	S.S.	S.M.	F.V.	F.D.	S.S.	S.M.	F.V.
Burning with flame (CWF)																
sc	4	2810.38	702.59	304.83*	4	384177928	960444821	211.41*	4	146403.2	36601	216.96*	4	6014.52	1503.63	72.04*
vt	2	12.40	6.20	2.69	2	76226297	38113148	8,39*	2	576.41	288.21	1.71	2	75.96	37.98	1.82
im	2	49.65	24.83	10.77*	2	51910884	25955442	5.71*	2	58.49	29.2	0.17*	2	305.04	152.52	7.31*
sc*vt	8	24.79	3.10	1.34	8	168296433	21037054	4.63*	8	4839.31	604.9	3.59*	8	450.78	56.35	2.70*
sc*im	8	83.39	10.42	4.52*	8	127413962	15926745	3.51*	8	1172.06	146.5	0.87	8	571.70	71.46	3.42*
vt*im	4	27.06	6.76	2.93**	4	25737996	6434499	1.42	4	3335.12	833.8	4.94*	4	352.25	88.06	4.22*
sc*vt*im	16	78.53	4.91	2.13**	16	25737996	6212826	1.37	16	12792.96	799.6	4.74*	16	1027.88	64.24	3.08*
Error	90	207.44	2.31		90	408872003	4543022		90	15183.06	168.7		90	1878.49	20.87	
Total	134	3293.64			134	479964207			134	184360.6			134	10676.6		
Burning without flame (CWOF)																
sc	4	5546.40	1386.35	652.81*	4	776315269	194078817	366.44*	4	432709.9	108177.5	170.79*	4	5109.62	1277.4	638.06*
vt	2	6.77	3.39	1.59	2	10353546	5176773	0.98	2	5106.41	2553.21	4.03**	2	6.32	3.16	1.58
im	2	14.50	7.25	3.41*	2	61503846	30751923	5.81*	2	822.18	411.09	0.65*	2	13.09	6.54	3.27*
sc*vt	8	6.12	0.77	0.36	8	38403590	4800449	0.91	8	15303.26	1912.91	3.02*	8	6.50	0.81	0.41
sc*im	8	56.14	7.02	3.30*	8	52355730	6544466	1.24	8	14635.76	1829.47	2.89*	8	52.77	6.6	3.29*
vt*im	4	34.24	8.56	4.03*	4	29506077	7376519	1.39	4	8612.55	2153.14	3.4**	4	32	8	4*
sc*vt*im	16	66.66	4.17	1.96**	16	268572322	16785770	3.17*	16	41028.69	2564.29	4.05*	16	63.78	3.99	1.99**
Error	90	191.13	2.12		90	476667857	5296310		90	57006.22	633.40		90	180.18	2	
Total	134	5920.95			134	870051566			134	575225.1			134	5464.26		

Burning during afterglow (CDA)																
sc	4	544.02	136.01	49.11*	4	177002538	442506347	59.65*	4	99503.10	24875.78	164.86*	4	566.88	141.72	54.72*
vt	2	7.44	3.72	1.34	2	6663726	3331863	0.45	2	134.04	67.02	0.44	2	5.3	2.65	1.02
im	2	8.43	4.21	1.52*	2	76919454	38459727	5.18*	2	257.84	128.92	0.85*	2	5.27	2.63	1.02*
sc*vt	8	34.23	4.28	1.54	8	126479058	15809882	2.13**	8	3467.22	433.40	2.87*	8	29.96	3.75	1.45
sc*im	8	28.73	3.59	1.30	8	156744361	19593045	2.64**	8	3669.99	458.75	3.04*	8	21.74	2.72	1.05
vt*im	4	67.66	16.91	6.11*	4	204199114	51049779	6.88*	4	414.33	103.58	0.69	4	80.78	20.2	7.8*
sc*vt*im	16	203.48	12.72	4.59*	16	406678687	25417418	3.43*	16	12426.07	776.63	5.15*	16	181.73	11.36	4.39*
Error	90	249.27	2.77		90	667660769	7418453		90	13579.87	150.89		90	233.082	2.59	
Total	134	1143.25			134	341537055			134	133452.5			134	1124.74		

F.D.: Degrees of freedom, S.S.: Sum of squares, S.M.: Mean of squares, F.V.: F Value, sc: Change of seasonal, im: Materials of impregnate, vt: Types of varnish.

Tab. 5: Mean values of the flue gas composition and the groups resulting from the least significant difference (LSD) analysis.

Faktor	***Burning with flame (CWF)***				***Burning without flame (CWOF)***				***Burning during afterglow (CWOF)***			
	O_2 (%)	**CO_2 (%)**	**CO (ppm)**	**NO (ppm)**	**O_2 (%)**	**CO_2 (%)**	**CO (ppm)**	**NO (ppm)**	**O_2 (%)**	**CO_2 (%)**	**CO (ppm)**	**NO (ppm)**
Change of seasonal (SC)												
Winter	16.34 ^{a}	4.00 ^{d}	11935 ^{d}	13.61 ^{c}	18.76 ^{a}	2.21 c	10887 ^{d}	36.8 ^{bc}	14.11 ^{b}	6.57 ^{c}	17791 ^{a}	24.47^{d}
Spring	2.79 ^{e}	24.23 ^{a}	28483 ^{a}	97.28 ^{a}	5.54 ^{b}	14.80 ^{b}	15666 ^{c}	175.6 ^{a}	15.69 ^{a}	4.57 ^{d}	7998 ^{c}	92.33^{a}
Summer	9.26 ^{c}	12.86 ^{b}	19843 ^{b}	35.97 ^{b}	6.28 ^{b}	14.18 ^{b}	22162 ^{b}	32.80 ^{c}	12.54 ^{c}	7.89 ^{b}	14308 ^{b}	14.34^{e}
Fall	7.74 ^{d}	12.74 ^{b}	20963 ^{b}	8.78 ^{c}	1.29 ^{c}	19.02 ^{a}	29300 ^{a}	46.83 ^{b}	11.02 ^{d}	9.52 ^{a}	15569 ^{b}	52.10^{b}
Investigated	12.56 ^{b}	8.91	17883 ^{c}	14.96 ^{c}	1.29 ^{c}	18.95 ^{a}	30431 ^{a}	24.42 ^{c}	10.17 ^{d}	10.27 ^{a}	17890 ^{a}	39.13^{c}
Ort.	9.74	12.55	19821	34.12	6.63	13.83	21689	63.29	12.71	7.76	14711	44.47
Sx	5.10	7.47	5964	36.82	7.17	6.88	8478	63.30	2.25	2.29	4048	30.35
LSD	0.8209	2.4703	1152.5	7.0229	0.788	0.7651	1244.4	13.608	0.8999	0.8702	1472.7	6.6418
Types of varnish (VT)												
Water-based	9.74 ^{ab}	11.85 ^{a}	20379 ^{a}	32.65 ^{a}	6.44 ^{a}	14.00 ^{a}	22071 ^{a}	64.87^{ab}	13.03 ^{a}	7.50 ^{a}	14573 ^{a}	43.49^{a}
Synthetic	10.11 ^{a}	13.59 ^{a}	18759 ^{b}	37.04 ^{a}	6.50 ^{a}	13.96 ^{a}	21576 ^{a}	69.92 ^{a}	12.49 ^{a}	7.82 ^{a}	14535 ^{a}	44.09^{a}
Investigated	9.37 ^{b}	12.20 ^{a}	20326 ^{a}	32.67 ^{a}	6.95 ^{a}	13.53 ^{a}	21422 ^{a}	55.10 ^{b}	12.60 ^{a}	7.97 ^{a}	15025 ^{a}	45.84^{a}
Ort.	9.74	12.55	19821	34.12	6.63	13.83	21690	63.30	12.71	7.76	14711	44.47
Sx	0.37	0.92	920.39	2.53	0.28	0.26	339.10	7.53	0.29	0.24	272.59	1.22
LSD	0.6359	1.9135	892.7	5.4399	0.6104	0.5926	963.88	10.541	0.697	0.697	1140.1	5.1447
Materials of impregnate (IM)												
Tanalith-E	8.88 ^{b}	14.67 ^{a}	20658 ^{a}	33.45 ^{a}	6.31 ^{b}	14.12 ^{a}	22552 ^{a}	61.44 ^{a}	12.65 ^{a}	7.87 ^{a}	15234 ^{a}	46.40^{a}
Wolmanit-CB	10.19 ^{a}	11.56 ^{b}	19630 ^{b}	33.90 ^{a}	7.08 ^{a}	13.40 ^{b}	21612 ^{ab}	61.67 ^{a}	13.04 ^{a}	7.49 ^{a}	13644 ^{b}	43.21^{a}
Investigated	10.14 ^{a}	11.42 ^{b}	19176 ^{b}	35.02 ^{a}	6.50 ^{ab}	13.97^{ab}	20904 ^{b}	66.79 ^{a}	12.44 ^{a}	7.93 ^{a}	15255 ^{a}	43.82^{a}
Ort.	9.74	12.55	19821	34.12	6.63	13.83	21689	63.30	12.71	7.76	14711	44.48
Sx	0.74	1.84	759	0.81	0.40	0.38	826.72	3.02	0.30	0.24	924	1.69
LSD	0.6359	1.9135	892.7	5.4399	0.6104	0.5926	963.88	10.541	0.697	0.674	1140.1	5.1447

The differences in the O_2, CO_2, CO and NO content of the flue gas released during the burning of the impregnated cedar wood samples with or without flame or during afterglow were determined to be significant at a threshold of 1 % for the seasonal effects and for the type of impregnating chemical. The difference in the NO content was determined as significant at a threshold of 5 % for the varnish type (Tab. 4).

The results of the flue gas analysis indicated the highest mean O_2 content in winter samples during CWF and CWOF was 16.34 and 18.76 %, respectively, and in spring samples during CWOF was 15.69 %. The lowest CO content was determined in winter samples during CWF and CWOF at 11935 and 10887 ppm, respectively, and in spring samples during CDA at 7998 ppm. The lowest CO_2 content was measured in winter samples during CWF and CWOF at 4.00 and 2.21 %, respectively, and in spring samples during CDA at 4.51 %. The highest NO content was determined in summer samples during CWF as 35.97 ppm and in spring samples during CWOF and CDA as 175.6 and 92.33 ppm, respectively. 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 and NO contents were higher during CWF and CWOF. On the other hand, the CO_2 content of the samples that were impregnated with Wolmanit-CB was higher than those that were impregnated with Tanalith-E during CDA while the O_2, CO and NO contents were determined to be lower. An investigation of the effect of varnish type during CWF, CWOF and CDA revealed that the O_2, CO_2 and NO contents of the samples treated with synthetic varnish were higher than those treated with water-based varnish whereas the CO content was lower during burning with flame; the O_2 and CO contents were higher and the CO_2 and NO contents were lower during combustion without flame. During afterglow, the CO_2 and NO contents were higher and O_2 and CO contents were lower and the O_2, CO and NO contents were higher (Tab. 5).

The temperature of burning was the highest in the control samples, in those impregnated with Wolmanit-CB and those that were treated with water-based varnish. Burning temperature of control samples are the same as Temiz et al. 2008.

The weight loss was reported as 94 % for scots pine control samples in a previous study (Atilgan and Peker 2012). The weight loss of the chestnut wood samples were determined as 84.65 % in the present study. This value was higher than those reported for Scots pine samples. This is thought to be a result of the existence of extractive materials in chestnut and Scots pine wood samples.

Earlier studies reported the highest mean O_2 content as 18.6 % for sapelli wood samples impregnated with boric acid and treated using polyurethane varnish, whereas the lowest was reported as 14.07 % for samples impregnated with Tanalith-E and treated using water-based varnish. The highest CO content was determined as 4917.98 ppm for sapelli wood impregnated with Tanalith-E and treated with water-based varnish, whereas the lowest value was reported as 540.78 ppm for samples that were impregnated with borax and treated with polyurethane varnish. The highest NO value was determined as 152.41 ppm for sapelli wood samples impregnated with Tanalith-E and treated with water-based varnish, whereas the lowest value was determined as 540.78 ppm for the control samples impregnated with boric acid and treated with water-based varnish (Uysal et al. 2011).

CONCLUSIONS

The highest illuminance, which was determined for the impregnated samples, was determined for the spring samples with respect to the seasonal changes during CWF, CWOF and CDA and for those samples that were treated with synthetic varnish in comparison to those samples that were treated with water-based varnish during CWF, CWOF and CDA. Impregnation with Wolmanit-BC or Tanalith-E yielded similar outcomes during CWF, CWOF and CDA.

The highest temperatures of burning of chestnut wood was determined for the investigated samples with respect to the seasonal changes during CWF, CWOF and CDA, for those samples that were impregnated with Wolmanit-CB rather than with Tanalith-E, and for those samples that were treated with water-based varnish in comparison to those samples that were treated with synthetic varnish during CWF, CWOF and CDA.

The measured burning parameters indicated that the time to collapse (CTV) was the longest for the spring samples, whereas the total duration of burning (CTT) was the longest for the summer samples with respect to the seasonal changes. The CTV and CTT of the samples that were impregnated with Wolmanit-CB were longer than those that were impregnated with Tanalith-E. Burning parameters were similar upon treatment with either synthetic or water-based varnish.

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

The highest O_2 content of the flue gas of combustion occurred in the winter samples during CWF and CWOF and for the spring samples during CDA with respect to the seasonal changes; correspondingly the lowest CO and CO_2 contents were determined for those same samples. The highest NO content was determined for the summer samples during CWF and for the spring samples during CWOF and CDA. The CO_2 and CO contents of the samples that were impregnated with Wolmanit-CB were lower and their O_2 and NO contents were higher than those that were impregnated with Tanalith-E during CWF and CWOF. On the other hand, the CO_2 content of the samples that were impregnated with Wolmanit-CB was higher and their O_2, CO and NO contents were lower than those that were impregnated with Tanalith-E during CDA with respect to the effect of the type of impregnating material. The O_2, CO_2 and NO contents of the samples that were treated with synthetic varnish were higher and the CO content was lower than those samples that were treated with water-based varnish during burning with flame. During combustion without flame, the O_2 and CO contents were higher whereas the CO_2 and NO contents were lower. During afterglow, the CO_2 and NO contents were higher whereas the O_2 and CO contents were lower and the O_2, CO and NO contents were higher with respect to the effect of the type of varnish.

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S. Sadiye Yasar
Gumushane University
Gumushane Vocational High School
Department of Desing
29100, Gumushane
Turkey

*Muhammed Said Fidan
Gumushane University
Institute of Natural Applied Science
Department of Forestry and Evironment Sciences
29100 Gumushane
Turkey
Phone: +90 (456) 233 1060/2926
Corresponding author: saidfidan@gumushane.edu.tr

Mehmet Yasar
Gumushane University
Gumushane Vocational High School
Department of Desing
29100, Gumushane
Turkey

Musa Atar
Gazi University
Faculty of Technology
Department of Wood Products Industrial Engineering
06500 Ankara
Turkey

Elif Alkan
Gumushane University
Institute of Natural Applied Science
Department of Forestry and Evironment Sciences
29100 Gumushane
Turkey