Determining the Effect of Seasonal Variation in Spruce (*Picea orientalis* L.) Wood Treated with Various Impregnations on Combustion Resistance

Ş. Şadiye Yasar,[a,]* M. Said Fidan,[b] Mehmet Yaşar,[c] Musa Atar,[d] and Elif Alkan [e]

Prepared test specimens were surface treated and coated with synthetic and water-based outdoor varnishes after being chemically impregnated. The test specimens were left outdoors to determine the effects of impregnation and treatment on the wood during each of the four seasons. Caucasian spruce (*Picea orientalis* L.) test specimens were prepared and combustion analyses were performed. As a result of the combustion test, weight loss results, as compared with the control, were 89% lower in the spring specimens, 90% lower with impregnation, and 90% lower with the synthetic varnish coating. Furthermore, the O_2 amount during combustion was found to be the highest in combustion with a flame source in the winter specimens (21%). The CO_2 amount was the highest in combustion without a flame source for full-year specimens (20%). The CO amount was the highest in combustion without a flame source of full-year specimens (31,787 ppm), and the NO amount was the highest during glowing of full-year specimens (55 ppm). Final results showed impregnation with Tanalith-E and water-based varnish coating to be the most effective fire protective treatments.

Keywords: Seasonal change; Combustion; Varnish; Spruce; Wood; Impregnation

*Contact information: a: Gumushane University, Gumushane Vocational High School, Department of Desing, 29100, Gumushane, Turkey; b: Gumushane University, Institute Of Natural Applied Science, Department of Forestry and Evironment Sciences, 29100, Gumushane, Turkey; c: Gumushane University, Gumushane Vocational High School, Department of Desing, 29100, Gumushane, Turkey; d: Gazi University, Faculty of Technology, Department of Wood Products Industrial Engineering, 06500, Ankara, Turkey; e: Gumushane University, Institute Of Natural Applied Science, Department of Forestry and Evironment Sciences, 29100, Gumushane, Turkey; *Corresponding author: ssyasar@gumushane.edu.tr*

INTRODUCTION

Wood is an indispensible material that has been used in internal and external decorations for centuries (Peker 1997; Sönmez and Budakcı 2004). Wood used as a construction material has superior properties as compared with other materials. However, wood is affected negatively by fire and biotic and abiotic pests under appropriate conditions because of its organic nature (Peker *et al.* 1999).

Wood is one of the most commonly used construction materials because it is an environmentally friendly and renewable natural source. There is an increasing demand for wood and wood-based composites for both indoor and outdoor building construction applications. It is relatively easily processed, has favorable physical and mechanical properties, has an aesthetic appearance, and has no harmful environmental or health impacts (Temiz *et al.* 2008; Qu *et al.* 2011).

The many applications of wood are due to its anatomical structure, physical and mechanical properties, and chemical structure (Bozkurt and Erdin 1997). Raw material wood is composed of carbon and hydrogen atoms; therefore, its combustion under suitable conditions is one of the downsides to its use. The few other negative aspects of wood materials cause only financial losses, whereas their flammability could result in life-threatening situations. Flames and released gases as a result of burning wood could threaten human life and cause death (Chin-Mu and Wang 1991; Terzi 2008).

Wood has to be treated with preservative chemicals (impregnation) to prevent damage to the wood and therefore prolong its life. Impregnations (the chemicals used for impregnation) have various properties according to their purpose of use. When these chemicals are applied, ideally they should not have any negative impact on the wood properties while showing a preservative effect (Richardson 1987).

Inorganic-based chemicals are the most commonly used substances to retard and prevent the combustion of wooden material. The most frequently used chemicals are ammonium sulfate, ammonium chloride, borax, boric acid, phosphoric acid, and zinc chloride (Browne 1963; Baysal 1994). Additionally, wood is usually surface-treated to protect it from the outer environment (biotic, abiotic pests, fire, *etc.*).

The aim of the present study was to investigate how various impregnations and wood surface treatments affect the combustion properties of seasonal wood.

EXPERIMENTAL

Materials

Specimens used in this study were obtained from spruce wood provided from the Eastern Black Sea Region by a "random selection" method. The selected wood was held in a climate chamber at a temperature of 20 ± 2 °C and 65 ± 3% relative humidity until it obtained a 12% moisture content and constant weight. Then, samples of wood were rough cut for experiments. Each chosen test specimen was carefully chosen to be knotless, non-resinous, free of growth defects, solid, smoothly fibered, and fresh (TS 2470 1976).

Wolmanit-CB and Tanalith-E were selected as the impregnations for this study, as they are the most commonly used impregnations for external environments in Turkey. Synthetic varnish, which is commonly used as an interior and exterior wall varnish, and a water-based varnish, which does not release harmful gases like synthetic and polyurethane varnish, were selected for the varnish type. The composition of Wolmanit-CB is 35% copper sulfate ($CuSO_4 \cdot 5H_2O$), 45% potassium dichromate ($K_2Cr_2O_7$), and 20% boric acid (H_3BO_3) (Berkel 1972). Tanalith from boron-impregnated materials was procured using arsenic instead of boron found in the salt types copper chrome boron and chromated copper arsenate (Yalınkılıç *et al.* 1998). This impregnate material is a water-based solution of copper triazol and does not contain chromium and arsenic.

Methods

The test specimens were cut evenly into 13 x 13 x 76 mm^3 dimensions. Three groups were prepared for each test period, with two different impregnations, two different varnish types, four seasons, and control groups; a total of 24 test specimens were prepared (Table 1). Before impregnation, the test specimens were dried at 20±2 °C and 65±5% relative humidity until they reached constant weight and then were weighed on a precision balance with a 0.01 g precision. The test specimens were impregnated by a vacuum-pressure method in accordance with ASTM-D 1413-76 (1976). To accomplish this, the specimens were vacuumed under pressure equivalent to 60 cm hg^{-1} for 60 min and then placed in a solution under standard atmospheric pressure for 60 min according to TS 2471 (1976).

Table 1. Test Samples Prepared for the Present Study

Wood Type	Seasonal Groups	Impregnating Material	Varnish	Number
Picea orientalis L.	Spring	Wolmanit-CB Tanalith-E	Water-based varnish Synthetic varnish	24x3=72
	Summer			24x3=72
	Fall			24x3=72
	Winter			24x3=72
	Control			24x3=72

The retention of the impregnation in the test specimens (r-kg/m^3) was determined by weighing the specimens before and after impregnation and using Eq. 1 (TS 5724, 1988),

$$R = \left[\frac{\mathrm{G.C}}{V}\right] \times 10^{3}\, kg/m^{3} \qquad (1)$$

where G is calculated as $T_2 - T_1$, for which T_1 is the weight of the test specimen before impregnation (g) and T_2 is the weight of the test specimen after impregnation (g); V is the specimen volume (cm^3); and C is the solution concentration (%).

Average retention values (kg/m^3) of the test specimens were determined to be 1.15 kg/m^3 for Tanalith-E and 6.35 kg/m^3 for Wolmanit-CB.

The impregnated specimens were held in an environment with air circulation for 15 to 20 days to evaporate the solvent. They were then exposed to a drying process at 20±2 °C and 65±3% relative humidity until they reached 12% humidity. Varnishing treatment was then performed in accordance with the requirements of ASTM-D 3023 (1988). After impregnation, the surfaces of the acclimatized specimens were slightly sanded with a No. 220 sander and cleaned of dust for varnishing. The varnishes to be applied to the surface of the specimens were weighed with an electronic scale of 0.01 g precision according to the advice of the manufacturer regarding the amounts to be applied. The test specimens were then dried at room temperature and later exposed to external factors on stands previously prepared depending on periods (summer, autumn, winter, and spring). The specimens were positioned on the test stand, facing south at a 45° angle. In this study, the effects of external factors on the combustion properties of the wooden materials were investigated. For this reason, the specimens were periodically left in an outdoor environment together with control groups in the following order: Spring (between 3 and 6 months), summer (between 6 and 9 months), autumn (between 9 and 12 months) and winter (between 12 and 3 months). At the end of weathering, combustion tests were conducted (Özçifçi and Batan 2009).

The specimens – impregnated and not impregnated, varnished and not varnished – were taken from the external medium at the end of their respective periodic duration, and their combustion properties were measured in accordance with ASTM-E 160-50 (1975). Each specimen group was weighed and placed on a wire-stand in the device. In the experiment, the 24 specimens were placed on top of each other 12 specimens high in the shape of a square prism. A flame source was placed under the stack, and combustion with flame source (CWFS) was pursued for three minutes. Afterwards, the flame source was extinguished to proceed with combustion without a flame source (CWTFS) and after glow (G) stages. Temperature was recorded in °C at the burning column by a thermocouple at 15 s, 30 s, and thereafter at 30-s intervals for CWFS, CWTFS and G, respectively. The smoke density was measured by a device (GEMO-DT 742, Tectis, Gürbüzoğlu Electronic, Ankara/Turkey) placed 30 cm from the flame outlet chimney. The device measured the light density (LD) coming out of a 100 candela light source. The light density changed according to the formed smoke and was measured by a photocell detector (LD was measured in units of lux) (Baysal *et al.* 2003).

After burning, the specimens were weighed and the % weight loss was calculated using Eq. 2,

$$WL(\%) = \left[\frac{(W_0 - W_d)}{W_0} \right] \times 100 \tag{2}$$

where WL represents the weight loss (%), W_0 is the dry specimen weight before combustion (g), and W_d is the dry specimen weight after combustion (g).

During combustion, the self-combustion duration (s), glowing duration (s), total combustion duration (s), degradation time (s), and weight loss (%) were all determined. Then, measurement of the gases released during combustion with the flame source, without the flame source, and glowing was performed with a Sigma flue gas analyzer (MRU, Sigma, Esa Electronic, Germany) placed on the upper side of the combustion device chimney. Oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO), and nitrogen monoxide (NO) contents (%) were measured.

In data analysis, the gas amount, temperature, combustion duration, and weight loss ratios regarding combustion with the flame source, combustion without the flame source, and glowing were determined with analysis of variance in three repetitions using SAS software according to random block test patterns (SAS 1989). Furthermore, correlations between the gas amount, temperature, combustion duration, and weight loss ratios regarding combustion with the flame source, combustion without the flame source, and glowing were performed using SAS packaged software. The least significant difference test (LSD) was used for comparing the average values (SAS 1989).

RESULTS AND DISCUSSION

Analysis of variance results for weight loss of the impregnated spruce specimens in combustion with the flame source, combustion without the flame source, and glowing according to seasonal variation, impregnation, and varnish type are given in Table 2. The average values and least significant difference (LSD) test results are given in Table 3.

As a result of the analysis of variance regarding the weight loss of the impregnated spruce wood specimens, differences at a significance level of 0.01 between seasonal variation and varnish type were found (Table 2).

Table 2. Results of Analysis of Variance Regarding Weight Loss

Variation Source	Weight Loss (%)			
	Degrees of Freedom	Sum of Squares	Mean Squares	F- Value
Seasonal Change (sc)	4	342.1	85.5	49.02**
Varnish Type (vt)	2	37	18.5	10.6**
Impregnate (i)	2	10.8	5.4	3.08
sc*vt	8	16.1	2	1.15
sc*i	8	51.2	6.4	3.67**
i*vt	4	23.8	6	3.41*
sc*i*vt	16	75.7	4.7	2.71**
Error	90	157	1.7	
Total	134	713.6		
* and ** - Significant at the level of 5% and 1%, respectively				

Table 3 shows the average values and least significant difference (LSD) test results for three factors tested (seasonal change, varnish type, and impregnate). For each factor, the temperatures and light density for the three combustion stages and the combustion durations and weight loss are shown.

The average weight loss during combustion according to seasonal variation was found out to be the lowest for the spring specimens (89%). The weight loss was higher with the Wolmanit-CB impregnation (91.06%) compared to the Tanalith-E impregnation (90.65%). It was lower in the synthetic varnish type (90.01%) compared with the water-based varnish type (90.78%).

According to the results obtained, the weight loss of spruce wood during combustion varied between seasons, being the lowest in the spring, and being lower with Tanalith-E and when synthetic varnish was used.

A literature review shows that the weight loss of yellow pine control specimens was 94% and weight loss of beech wood (wood examples impregranted with ammonium tetra fluoro borate (1 to 3%) and the mixture of cement and borax (6 to 9%) according to ASTM-D 1413-76 standards) was 92% (Atılgan and Peker 2012). In the present study, the weight loss of the control spruce wood was found to be 90.37%. This lower weight loss for spruce as compared with yellow pine and beech might be due to the different extractive materials contained in the woods.

The combustion weight loss of the impregnated wood according to seasonal variation is shown in Fig. 1. The weight losses with respect to the impregnation and varnish type are given in Fig. 2.

For the seasonal variation analysis, the lowest weight loss was observed in spring and the highest was in winter (Fig. 1). For the impregnations, the Tanalith-E impregnated specimens yielded lower results than the Wolmanit-CB impregnated specimens. For varnish type, the synthetic varnish-coated specimens yielded lower results than the water-based varnish-coated specimens (Fig. 2).

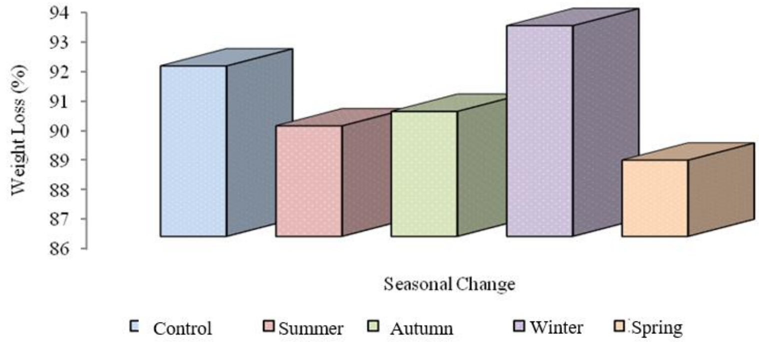

Fig. 1. Combustion weight loss of seasonal spruce wood

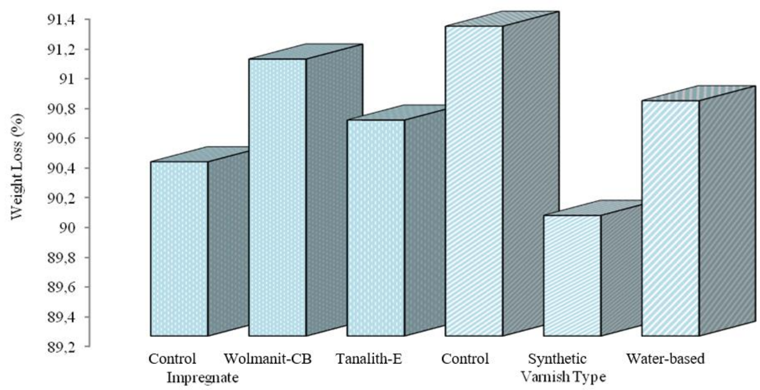

Fig. 2. Combustion weight loss of spruce wood according to impregnation and varnish type

Table 3 shows the average value of the total combustion and degradation duration of the wood according to seasonal variation. The highest total combustion duration was found in the spring specimens, at 408 s, and the highest degradation duration was that of the control specimens, at 626 s. The total combustion and degradation duration of the Wolmanit-CB impregnation wood (553 and 370 s, respectively) was lower than that of the Tanalith-E impregnation wood (556 and 356 s, respectively). The total combustion and degradation duration of the water-based varnish-coated specimens (557 and 374 s, respectively) was lower than that of the synthetic varnish-coated specimens (578 and 379 s, respectively).

Table 3 also shows the average temperatures of the combustion with flame source, combustion without flame source, and glowing. According to seasonal variation, the average temperatures of combustion with flame source and glowing were the highest in the spring specimens (484 and 332 °C, respectively), and the average temperature of combustion without flame source was the highest in the winter specimens (583 °C). As for the impregnations, the temperatures of combustion with flame source and without flame source of the Tanalith-E impregnation wood (480 and 571 °C, respectively) were higher than those of the Wolmanit-CB wood (476 and 566 °C, respectively). The glowing temperature of the Tanalith-E wood (326 °C) was lower than that of the Wolmanit-CB wood (332 °C). The respective temperatures for varnish type were similar to those of the impregnations. The temperatures of combustion with flame source, without flame source, and glowing of the water-based varnish type (480, 567, and 337 °C, respectively) were higher than those of the synthetic varnish type (470, 565, and 301 °C, respectively).

In summary of Table 3, the temperatures of combustion with flame source and glowing of spruce wood was the highest in the spring specimens and the temperature of combustion without flame source of spruce wood was the highest in the winter specimens. Additionally, the Tanalith-E impregnation and the water-based varnish type had the higher wood combustion temperatures.

Table 3. Groups Formed Acording to Average Values (%) and Least Significant Difference (LSD) Test Results with Seasonal Variation.

Factor	Combustion With Flame Source		Combustion Without Flame Source		Glowing		Combustion Duration		Weight Loss
	CT[1] (°C)	LD[2] (lux)	CT[1] (°C)	LD[2] (lux)	CT[1] (°C)	LD[2] (lux)	FT[3] (sn)	TCT[4] (sn)	(%)
Seasonal Variation									
Control	480 a	289 3	602 a	289 e	333 a	290 e	351 c	626 a	91.77 b
Summer	467 b	455 a	559 c	451 a	314 b	444 a	382 b	589 b	89.74 c
Autumn	463 b	306 d	545 d	304 d	320 ab	309 d	350 c	511 c	90.23 c
Winter	485 a	327 c	583 b	324 c	318 ab	326 c	385 b	595 ab	93.13 a
Spring	484 a	400 b	554 c	371 b	332 a	376 b	408 a	473 d	88.58 d
Avr.	476	355	569	348	323	349	375	559	91
S_x	10.13	69.9	23.3	65.4	8.59	62	24.7	64	1,05
LSD	8.63	8.49	11.9	2.45	15.9	7.64	16.4	32.7	0.71
Impregnate Materials									
Control	473 b	352 b	569 a	346 b	312 b	344 b	374 a	566 a	90.37 b
Wolmanit-CB	476 ab	361 a	566 a	350 a	332 a	352 a	370 a	553 a	91.06 a
Tanalith-E	480 a	354 b	571 a	348 a	326 a	351 a	381 a	556 a	90.65 ab
Avr.	476	355	569	348	323	349	375	559	91
S_x	3.51	4.73	2.52	2	10.26	4.36	5.57	6.81	0.35
LSD	6.69	6.58	9.26	1.9	12.3	5.92	12.7	25.3	0.55
Varnish Type									
Control	476 a	354 ab	574 a	350 a	333 a	353 a	372 a	540 b	91.28 a
Synthetic	470 b	351 b	565 b	347 b	301 b	350 ab	379 a	578 a	90.01 b
Water-based	480 a	360 a	567ab	348 b	337 a	345 b	374 a	557 ab	90.78 a
Avr.	476	355	569	348	323	349	375	559	91
S_x	5.03	4.58	4.73	1.53	19.73	4.04	3.61	19.04	0.64
LSD	1.99	6.58	9.26	1.9	12.32	5.92	12.73	25.31	0.55
CT[1]: Combustion temperature. LD[2]: Light density. FT3: Failure time. TCT4: Total combustion time, a-e: Significance level for LSD test									

Regarding the measured average temperature (°C) values during combustion, the highest value was obtained in Tanalith-E impregnated wood and water-based varnish-coated wood. The lowest temperature was found in specimens that were boric acid-impregnated and polyurethane varnish-coated (Uysal *et al.* 2011). The data obtained by Uysal *et al.* (2011) present similarities with the findings in the present work.

The average values of light densities during combustion with flame source, combustion without flame source, and glowing are also shown in Table 3. As for the seasonal variation, the light densities were the highest in the summer specimens: 455, 451, and 444 lux, respectively. The light densities of the Tanalith-E impregnated-wood during combustion with flame source, without flame source, and glowing (354, 348, and 351 lux, respectively) were slightly less than those of the Wolmanit-CB wood (361, 350, and 352 lux, respectively). The light densities of the water-based varnish type wood during combustion with flame source and without flame source (360 and 348 lux, respectively) were slightly greater than those of the synthetic varnish wood (351 and 347 lux, respectively). The light density of the water-based varnish wood during glowing (345 lux) was slightly less than that of the synthetic varnish wood (350 lux).

Table 4 shows the gas analysis results for the three factors tested during the three stages of combustion. For the seasonal variation, the lowest O_2 (%), CO_2 (%), CO (ppm), and NO (ppm) amounts during combustion with flame source were respectively 14.79% (summer), 0.68% (winter), 10.272 ppm (autumn), and 4.71 ppm (autumn). The highest amounts were 20.53% (winter), 15.99% (spring), 21.762 ppm (spring), and 40.61 ppm (autumn), respectively. For the combustion without flame source, the lowest amounts were 3.94% (spring), 9.16% (autumn), 19.687 ppm (autumn), and 3.25 ppm (autumn), respectively. The highest were, respectively, 11.16 % (autumn), 16.44% (spring), 27.119 ppm (winter), and 118.94 ppm (spring). During glowing, the lowest amounts were, respectively, 7.29% (winter), 5.09% (spring), 7734 ppm (spring), and 13.88 ppm (autumn). The highest were, respectively, 15.47% (spring), 13.18% (autumn), 25.820 ppm (autumn), and 79.88 ppm (spring).

Also shown in Table 4 is the gas analysis as a result of the impregnation. The O_2 amount from the Wolmanit-CB impregnated specimens was low, and the NO amount of the Wolmanit-CB impregnated specimens during combustion with flame source and glowing were higher than combustion without flame source. The CO_2 and CO amounts from the Wolmanit-CB impregnated specimens during combustion with flame source and glowing were higher than combustion without flame source.

According to the gas analysis results of the impregnated spruce wood during combustion with flame source, without flame source, and glowing, the water-based varnish-coated specimens had a higher O_2 amount than those applied with synthetic varnish. In contrast, the CO_2, CO, and NO amounts were lower than those of specimens applied with synthetic varnish (Table 4).

A literature review provided gas analysis results obtained from LVL specimens of laminated wood materials produced from yellow pine wood. The impregnated specimens burned less compared to the control specimen during combustion with flame source and without flame source. There was also a lower O_2 amount as compared to the control specimen. Due to the fact that self combustion continued in the control specimen after the flame source was removed from the flame chimney, the CO amount was greater (Özen *et* *al.* 2000). The combustion test data obtained by Özen *et al.* (2000) are similar to the results obtained in the present work.

Table 4. Groups Formed according to Average Values and Least Significant Difference (LSD) Test of Gas Analysis in Combustion with Flame Source, Without Flame Source, and Glowing

Factor	Combustion With Flame Source				Combustion Without Flame Source				Glowing			
	O_2 (%)	**CO_2 (%)**	**CO (ppm)**	**NO (ppm)**	**O_2 (%)**	**CO_2 (%)**	**CO (ppm)**	**NO (ppm)**	**O_2 (%)**	**CO_2 (%)**	**CO (ppm)**	**NO (ppm)**
Seasonal Change												
Control	15.84 d	4.8 c	11816 c	7.25 d	2.45 d	17.6 a	29642 a	20.37 c	10.51b	9.58 c	17213 d	39.31 b
Summer	14.79 d	6.12 b	14267 b	15.81b	6.92 b	13.5 b	23422 c	35.21 b	9.7 c	10.85b	19359 c	41.13 a
Autumn	18.16 b	2.75 d	10272 d	4.71 d	11.16a	9.15 c	19687 d	3.25 d	7.28 d	13.18a	25820 a	13.88 c
Winter	20.53 a	0.68 e	10422 d	11.22c	6.21 b	14.29b	27119 b	22.76 c	7.29 d	13.11a	22388 b	39.64 b
Spring	5.50 e	15.99a	21762 a	47.78a	3.94 c	16.44a	21324 d	118.94 a	15.47a	5.09 d	7734 e	79. 88a
Avr.	14.96	6.06	13708	17.35	6.13	14.19	24239	40.11	10.05	10.36	18503	42.77
S_x	5.73	5.92	4779	17.52	3.33	3.26	4104	45.52	3.86	3.8	6837	13.1
LSD	0.77	0.73	1353	3.87	1.41	1.36	2059	7.39	0.77	0.76	1584	5.63
Impregnate												
Control	15.03 a	6.19 a	13983 a	16.55a	5.74 a	14.35a	24772 a	35.54 b	9.81 a	10.57a	19831 a	40.58 a
Wolmanit-CB	14.95 a	6.05 a	13926 a	17.85a	5.96 a	14.35a	24603 a	42.00 a	9.98 a	10.5ab	18211 b	44.41a
Tanalith-E	14.91 a	5.96 a	13214 a	17.66a	6.72 a	13.69a	23342 a	42.77 a	10.36a	9.98 b	17466 b	43.32 a
Avr.	14.96	6.06	13708	17.35	6.13	14.19	24239	40.11	10.05	10.36	18503	42.77
S_x	0.08	0.12	428.48	0.7	0.51	0	781.41	3.97	0.28	0.32	1209.18	1.97
LSD	0.6	0.57	1048	3	1.09	1.05	1595	5.72	0.6	0.59	1227	4.36
Varnish Type												
Control	15.30 a	5.60 b	12613 b	16.65a	6.09 a	14.25a	24528 a	42.35 a	9.81 b	10.61a	18886 a	42.51 a
Synthetic	14.60 b	6.39 a	14405 a	19.05a	5.75 a	14.6 a	24499 a	42.58 ab	9.87 b	10.65a	18705 a	41.98 a
Water-based	14.98 ab	6.22 a	14106 a	16.35a	6.58 a	13.73a	23690 a	36.38 b	10.48a	9.83 b	17917 a	43.83 a
Avr.	14.96	6.06	13708	17.35	6.13	14.19	24239	40.11	10.05	10.36	18503	42.77
S_x	0.35	0.42	960.01	1.48	0.42	0.44	475.67	3.52	0.37	0.46	515.21	0.95
LSD	0.6	0.57	1048	3	1.09	1.06	1595	5.73	0.1	0.58	1227	4.36

a-e: Significance Level for LSD Test

The average values of the gas analysis results of CO and O_2 amounts during combustion with flame source, without flame source, and glowing were studied more closely. Figures 3, 4, and 5 show the analysis for the seasonal variation, impregnation, and varnish type, respectively.

For the varnish-coated specimens, during combustion with flame source, the highest O_2 amount was observed in the control specimen and the lowest in the synthetic varnish-coated specimens (Fig. 5). For the impregnations, the highest CO amount was in the control specimens, while the Tanalith-E impregnated wood had less CO than that of the Wolmanit-CB wood (Fig. 4). For the impregnated wood and varnished wood, the greatest CO amount was found during combustion without flame source. It is suggested that the CO amount increased due to the fact that self-combustion continued after the flame source was removed from the flame chimney.

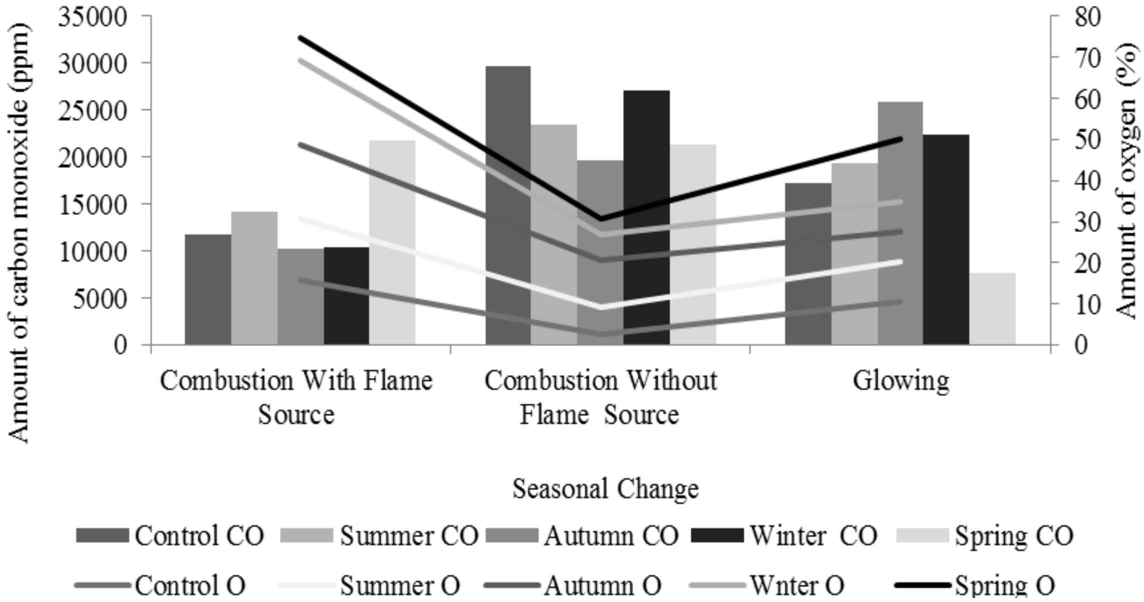

Fig. 3. Average gas analysis values of CO and O_2 amounts during combustion with flame source, without flame source, and glowing with respect to seasonal variation in spruce wood

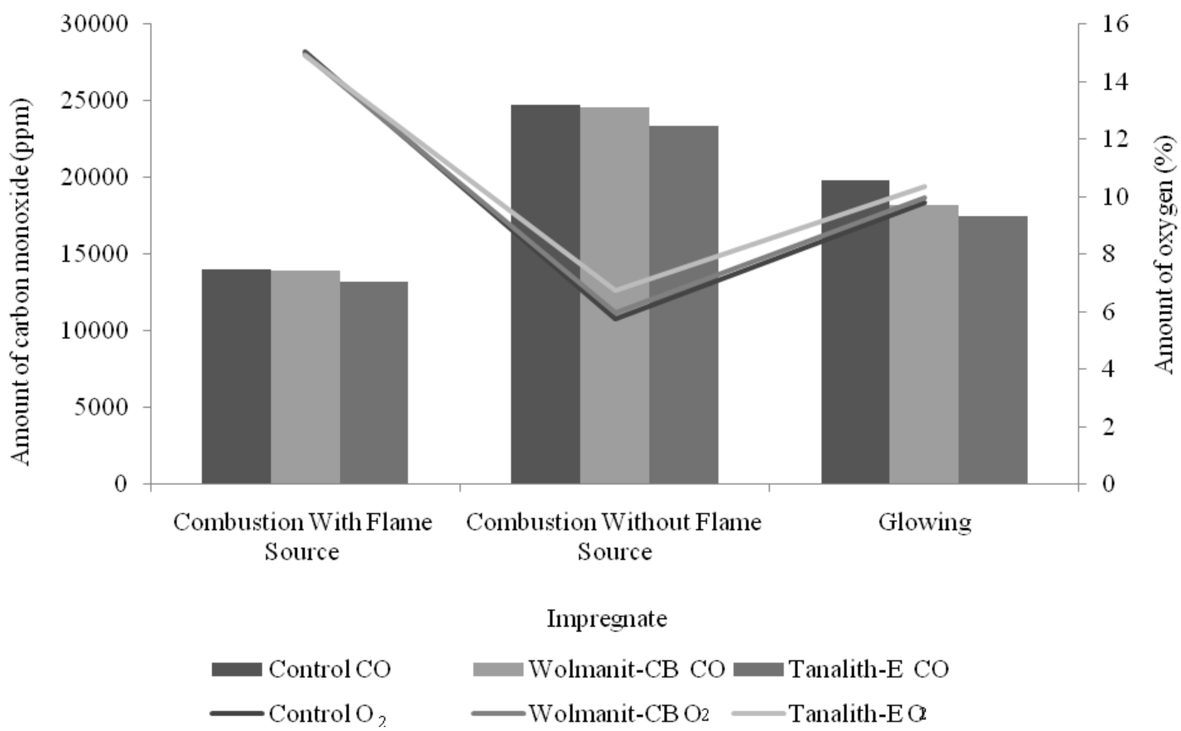

Fig. 4. Average gas analysis values of CO and O_2 amounts during combustion with flame source, without flame source, and glowing according to the type of impregnate

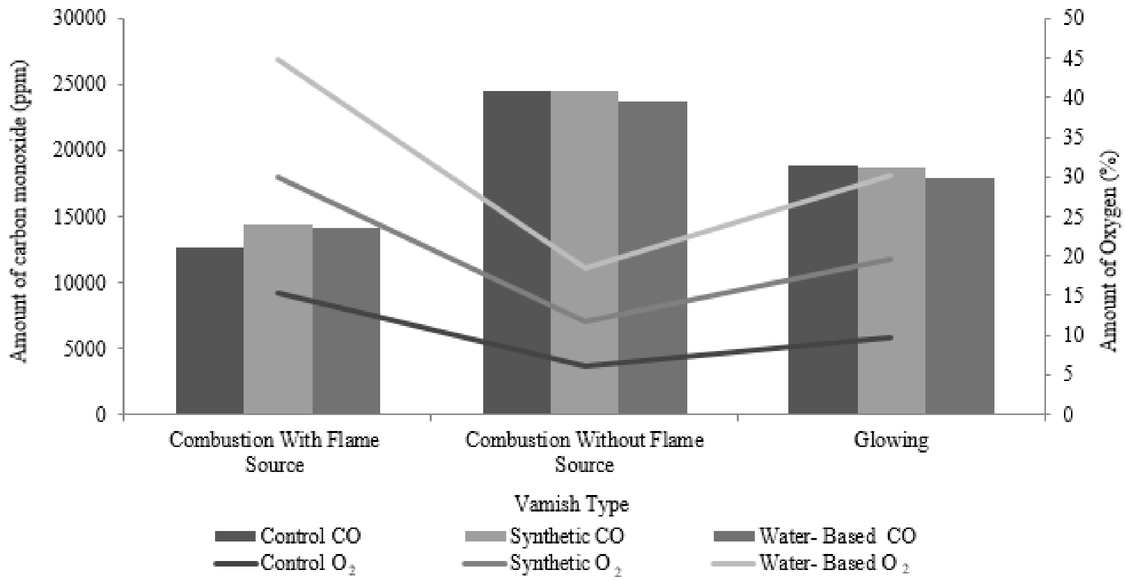

Fig. 5. Average gas analysis values of CO and O_2 amounts during combustion with flame source, without flame source, and glowing according to varnish type

CONCLUSIONS

1. According to the average weight loss values measured as a result of combustion tests, the highest weight loss of spruce according to impregnation interaction was obtained in the Wolmanit-CB impregnated specimens. This is because of the high retention of Wolmanit-CB impregnation. According to varnish type interaction, the highest weight loss was observed in the control specimens and the lowest in the synthetic varnish-coated specimens. These two results may be interpreted as the Tanalith-E impregnated wood and synthetic varnish-coated wood having fire-preventing properties.
2. When the average temperature values as a result of combustion tests were studied, the highest temperatures were observed with the Tanalith-E impregnated and water-based varnish-coated specimens.
3. In combustion with flame source, the highest O_2 amount was observed in the control specimen, and the lowest in the synthetic varnish-coated specimens. In combustion with flame source, because the impregnated and varnished specimens burned less than the control specimen, the decrease in O_2 amount was less compared with that of the control specimen. In combustion without flame source and glowing, the highest O_2 amount was observed in the Tanalith-E impregnated and water-based varnish-coated specimens and the lowest in the control specimens. The average values of the interaction between CO_2 amounts during combustion with flame source, without flame source, and glowing and between seasonal variation, impregnation, and varnish type were found to be the exact opposite of the average values of interaction between O_2 amounts, varnish type, and impregnation. The increase in CO amount, a sign of

combustion, was found to be the highest in the Wolmanit-CB treated specimens and lowest in the Tanalith-E treated specimens. In combustion with flame source, the highest CO amount was observed in the Wolmanit-CB treated specimens. In the control specimen, since self-combustion continued after the removal of the flame source from the flame chimney, the CO amount increased. Other impregnations showed a reducing effect on CO increase.

4. It is thought that wooden materials to be used in environments with fire hazard should not be varnish-coated after impregnation. In this study, the use of Tanalith-E for impregnation and synthetic varnish for varnish type showed favorable results.

ACKNOWLEDGMENTS

This study was supported by a scientific research Project (Project Number: 13.B0116.02.1), Gumushane University, Gumushane 2014 (in Turkish).

REFERENCES CITED

Atılgan, A., and Peker, H. (2012). "Some physical properties effects of various wood preservatives used in furniture and construction industry wood species," *Artvin Çoruh University Journal of Faculty of Forestry* 13(1), 67-78.

ASTM-D 1413-76 (1976). "Standart test methods of testing wood preservatives by laboratory soilblock cultures," ASTM International, West Conshohocken, PA.

ASTM-D 3023 (1988). "Practica for determination of resistance of factory applied coatings of wood products of stain and reagents," ASTM International, West Conshohocken, PA.

ASTM-E 160-50 (1975). "Standart test method for combustible properties of treated wood by the crib test," ASTM International, West Conshohocken, PA.

ASTM-E 69-02 (2007). "Standart test method for combustible properties of treated wood by the fire-tube apparatus," ASTM International, West Conshohocken, PA.

Baysal, E. (1994). *Several of the Compounds of Boron and WR Effect on Some Physical Properties of Pine Wood*, Master's Thesis, Institute of Natural Applied Sciences, Karadeniz Technical University, Trabzon, Turkey.

Baysal, E., Walker, H., Colak, M., and Tarımer, I. (2003). "Lacquered wood with boron compounds and burning characteristics of materials pre-retardant effect of the impregnation process," *Fırat University Journal of Science and Engineering* 15(4), 645-653.

Berkel, A. (1972). Wood Technology, Wood Materials Protection and Impregnation Technique. Istanbul University Faculty of Forestry Publication 183 (2). Press of Sermet, İstanbul, Turkey, 334.

Bozkurt, Y., and Erdin, N. (1997). "Wood technology," İstanbul University Faculty Publications: 3998, Number of Faculty Publications: 445, İstanbul, Turkey, p. 372.

Browne, F. (1963). *Theories of the Combustion of Wood and its Control*, Report No. 2136, U.S Forest Products Laboratory, Madison, WI.

Chin-Mu, T., and Wang, Y. L. (1991). "Incombustibility of fire retardant coated wood panels quart," *Journal Experimental Forest NTU* 5, 49-55.
Özen, R., Özçifçi, A., and Uysal, B. (2000). "The combustion properties of laminated wood materials prepared from scotch pine (*Pinus sylvestris L.*)," *Pamukkale University Engineering College Journal of Engineering Sciences* 7(1), 131-138.
Özçifçi, A., and Batan, F. (2009). "Effect of boron on mechanical properties of wood materials some oil," Gazi University *Journal of Polytechnic* 12(4), 287-292.
Peker, H. (1997). *The Effects of Agents Used in the Impregnation Varnish the Top Surface of the Furniture*, PhD Thesis, Department of Forest Industrial Engineering, Natural and Applied Sciences Institute, Karadeniz Technical University, Trabzon, Turkey.
Peker, H., Sivrikaya, H., Baysal, E., and Yalınkılıç, M. K. (1999). "Wood fire retardant and water-repellent effects on the bending resistance of chemical substances," *Pamukkale University Journal of Engineering Sciences* 5(1), 975-982.
Qu, H., Wu, W., Wu, H., Xie, J., and Xu, J. (2011). "Study on the effects of flame retardants on the thermal decomposition of wood by TG–MS," *Journal of Thermal Analysis and Calorimetry* 103(3), 935-942. DOI: 10.1007/s10973-010-1103-3
Richardson, B. A. (1987). *Wood Preservation*, The Construction Press Ltd., Lancaster, UK.
SAS (1989). Inc. SAS/STAT User's Guide (Release 6.0), SAS Institute, Cary, NC.
Sönmez, A., and Budakcı, M. (2004). *Wood Finishing Process in Woodworking II,* Sevgi Ofset, Ankara, Turkey.
Temiz, A., Gezer, E. D., Yildiz, U. C., and Yildiz, S. (2008). "Combustion properties of alder (*Alnus glutinosa* L.) Gaertn. Subsp Barbata (CA Mey) Yalt.) and southern pine (*Pinus sylvestris* L.) wood treated with boron compounds," *Construction and Building Materials* 22(11), 2165-2169. DOI: 10.1016/j.conbuildmat.2007.08.011
Terzi, E. (2008). *Characteristics Burning of Wood Material Impregnated with Ammonium Compounds*, Master's Thesis (unpublished), Department of Forestry Industry Engineering, Institute of Natural Applied Sciences, İstanbul University, İstanbul, Turkey.
TS 2470 (1976). "Samples for testing physical and mechanical rooms retrieval methods and general properties," Turkish Standards Institute, Ankara, Turkey.
TS 2471 (1976). "Wood, determination of moisture content for physical and mechanical tests" Turkish Standards Institute, Ankara, Turkey.
Uysal, B., Kurt, Ş., Esen, R., Özcan, C., Yıldırım, M. N., and Kılınç, İ. (2011). "Effects of combustion resistance of the top surface to the process on sapele wood impregnated with some chemicals," in: *6th International Advanced Technologies Symposium (IATS'11),* 16-18 May 2011, Elazığ, Turkey, p. 269.
Yalınkılıç, M. K., Z. Demirci, and E. Baysal. (1998). "Fire resistance of Douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco] wood treated with some chemicals," *J. Eng. Sci. Eng. College: Pamukkale Univ.* 4(12), 613-625.

Article submitted: June 15, 2016; Peer review completed: September 4, 2016; Revised version received and accepted: September 9, 2016; Published: September 21, 2016.
DOI: 10.15376/biores.11.4.9467-9479.