WOOD RESEARCH
64 (1): 2019
59-70

EFFECTS OF WOOD PRESERVATIVES ON THE COMBUSTION PROCESS AND COMBUSTION QUALITY OF WOOD

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(Received October 2018)

ABSTRACT

This study examines the combustion properties of Scots pine (*Pinus sylvestris* L.) and Oriental beech (*Fagus orientalis* L.) in 3 stages (CWF, SC and EC) according to ASTM E 160-50 (1975). Wood samples were impregnated with Tanalith-E (T) and Wolmanit-CB (WC) and then were varnished with Synthetic (St) and water based (wb) varnishes. When the combustion was completed, the weight loss, combustion temperatures, illuminance values, total time of combustion, and demolition time were measured.

As the result, illuminance value of Oriental beech wood decreased, while the smoke density increased. Scots pine was later destroyed in the combustion process. Areas with a risk of fire are advised to use pine wood instead of beech. Wolmanit-CB and synthetic varnish reduced the temperature and illuminance values. Oriental beech, Tanalith-E, and synthetic varnish resulted in the highest temperatures for all combustion stages. This triple interaction increased total combustion time values by more than 90% when compared with the control samples.

KEYWORDS: Wood, preservatives, impregnation, varnishes, combustion, illuminance.

INTRODUCTION

Wood is a valuable and abundant, renewable natural resource for construction and industrial materials. As the human population and its demand for food and land are continuing to grow, global forest resources have decreased by 50% over the past quarter of a century (FAO 2015). The timber production in Turkey for 2012 totaled 6.35 million m^3, 6.51 million m^3 in 2013, 6.66 m^3 in 2014, and 6.7 million m^3 in 2015 (OGM 2015).The sustainability of the procurement process for this material is increasingly a major problem (Komut and Ozturk 2017).

Since ancient times, various techniques and applications have been used to protect wood. Various furniture such as bed and cabinet made of wood has survived until today in the grave of the Egyptian Pharaoh Tutankhamen (Desroches 1963, Abdallah and Abdrabou 2018). These techniques can be similarly replicated today by applying protectors on the exposed portion of the wood to improve its durability against biological deterioration, flammability, and dimensional instability (Marney and Russell 2008, Toker et al. 2009, Clausen et al. 2010, Sandberg et al. 2017, Huang et al. 2012, Turkoglu et al. 2015, Uzun et al. 2016, Yasar et al. 2017).

In previous studies, chromated-copper-arsenate (CCA), pentachlorophenol, creosote, amine-copper-quaternary (ACQ), copper azole (CBA-Tanalith-E), and copper-chrome-boron (CCB) have been used to protect wood materials and composites (Ibach 2013, Rowell et al. 2014). Current wood preservatives should not be only resistant to ambient conditions and adhere well to the wood, but also be environmentally friendly and non-toxic (Zabel and Morrell 1992, Barnes 2001, EPA 2006, Reinprecht 2016).

The combustion of the cellulose, hemicellulose and lignin which is in the structure of the wood, follows a highly complicated physical and chemical process (see Fig. 1) (Reinprecht 2016, Rowell and Dietenberger 2013). Boron, chlorine, ammonium, phosphorus, and nitrogen compounds are used to protect wood materials and composites from burning (Ozcifci and Okcu 2008, Keskin et al. 2009, Stark et al. 2010, Atar et al. 2011, Ibach 2013, Bai et al. 2014, Gao 2014).

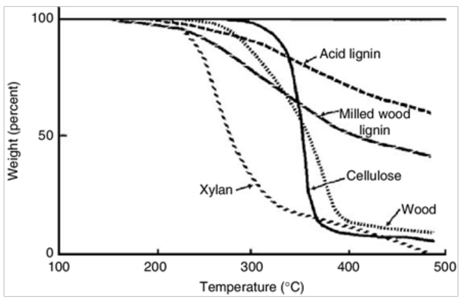

Fig. 1: Thermogravimetric analysis of cottonwood and its cell wall components (Rowell and Dietenberger 2013).

In the past studies, Oriental beech impregnated with Tanalith-E, Adulate KD-5 and Wolmanit CX-8 at 0.25, 1 and 4.7 concentrations were analysed by using thermal analysis, thermogravimetric analysis, differential-thermal analysis, and differential thermal analysis under an argon atmosphere. The temperature of the initial weight loss of pyrolysis (Ti) was lower than in untreated specimens and the amount of residual coal increased. Maximum degradation temperature (Tmax) values decreased as the concentration increased (Baysal et al. 2011).

Commercial wood preservatives (Vacsol Aqua, Imersol Aqua, Adolit BQ1, Wolmanit CB, and Tanalith C3310) at 4% concentration had different effects on the thermal behavior of Scots pine wood. The amount of char formation during the thermal degradation of the wood samples increased in control samples. The temperature of the initial weight loss of pyrolysis (Ti) and the temperature at the maximum rate of the wood pyrolysis (Tmax) in Wolmanit-CB treated samples were lower than control samples. In areas with a high risk of fire, use of Wolmanit-CB is recommended (Tomak et al. 2012).

Impregnating wood with protective materials is a widely used protection method (Hill 2006, Sandberg et al. 2017). In this experiment, oriental beech wood was impregnated with boric acid or borax, according to ASTM D 1413-76 (1976), by using a vacuum technique. The wood was then varnished with cellulosic, synthetic, polyurethane, water based, acrylic, or acid-hardening varnish. In non-flame source combustion, the highest combustion temperature was in boric acid plus water-based varnish, and lowest in boric acid plus synthetic varnish (Atar et al. 2011).

The aim of this study was to determine the combustion properties like temperatures, illuminance, weight loss, demolition time, and combustion duration of Oriental beech (*Fagus orientalis* L.) and Scots pine (*Pinus sylvestris* L.) wood treated with wood preservatives and varnishes.

MATERIALS AND METHODS

Materials

Scots pine (*Pinus sylvestris* L.) and Oriental beech (*Fagus orientalis* L.) wood were selected, as they are two of the most commonly used wood materials. The characteristics of the wood types utilized in this research are shown in Tab. 1. Wood materials were chosen with a random selection method from the Eastern Black Sea region in Turkey. Each selected test specimen was of high quality, knotless, non-resinous, defect-free, solid, and smooth fibered according to TS 2470 (1976).

Tab. 1: Characteristics of wood used in this research (Bozkurt and Erdin 2000, Kollman and Cote 1968, Tank 1978, Usta, 1989).

(δ_0, δ_{12}, δ_0)	Scots pine	Oriental beech
Density	0.49 ($g \cdot cm^{-3}$) 0.52 ($g \cdot cm^{-3}$)	0.68 ($g \cdot cm^{-3}$) 0.72 ($g \cdot cm^{-3}$)
Heat Value (Calorie)	5066 ($Cal \cdot kg^{-1}$)	4187 ($Cal \cdot kg^{-1}$)
Cellulose	54.8 %	41.5 %
Hemicellulose	16.8 %	37.4 %
Lignin	26.7 %	22.6 %
Ash	0.4 %	0.6 %

The wood samples were held in a climate-controlled chamber at a temperature of 20 ± 2°C and relative moisture content of 65 ± 3% until they obtained a 12% moisture content and constant weight.

Tanalith-E consists of a specific amount of a mixture of copper carbonate, 2-aminoethanol, boric acid, tebuconazole, propiconazole, polyethylene amine organic acid, and surfactant tebuconazole formulation (Safety Data Sheet 2004). Triazoles (tebuconazole, propiconazole) forming the content of Tanalith-E are the most widely used wood preservative impregnation agent against the destruction of fungi and fungal spores (Front Research 2016, Kukowski et al. 2017).

Wolmanit-CB consists of a mixture of copper sulfate, potassium dichromate, and boric acid (Berkel 1972). Copper+chromate+borate salts are widely used preservation in Europe (Barnes 2001, Reinprecht 2016). A concentrated amount of preservative materials affects combustion parameters. This research used oxygen index values to measure different concentrations of Wolmanit-CB flammability at the recommended 3% concentration (Donmez 2014). The 2.4% Tanalith-E and 4% Wolmanit-CB concentration ratios were obtained from Hemel Company and Emsan Company in Turkey.

Water based varnish and synthetic varnish were used to varnish the test specimens. Synthetic varnish is the solution of drying oils and oil alkyds modified with synthetic resins in turpentine, nephth and hydrocarbon group liquids (Sonmez and Budakci 2004). Water based varnish is colorless, odorless, non-yellowing, and it does not change the natural color of wood (Atar 1999). Manufacturer recommendations regarding the amount of varnish to be applied were followed.

Methods

The wood samples were cut to the dimensions of 13 x 13 x 76 mm for the combustion test prior to impregnating (radial x tangent x length). For each of the experimental applications, 24 pieces were cut in accordance with ASTM E 160-50 (1975). During impregnation treatments, wood was pressure impregnated with chemical solutions by using the procedure in ASTM-D 1413-76 (1976). After specimens were vacuumed under pressure equivalent to 600 mm Hg for 60 min, they were then placed in a solution under standard atmospheric pressure for 60 min. The impregnated samples were left in an air-circulated room for 15 to 20 days to allow them to reach to a constant weight. Following impregnation and acclimatization, the samples were varnished in compliance with the principles provided in ASTM-D 3023 (1988).

Before the combustion test, each experiment type group was weighed and stacked on a wire stand. The wire stand was placed at the exact center of the flame source on the combustion device. The combustion test was designed according to ASTM E 160-50 (1975).

The combustion test was carried out in 3 stages. After combustion with a fire source for 3 min (CWF), it was followed by self-combustion (SC), and finally, ember combustion (EC) of the wood without a fire source (Yasar et al. 2016). The CWF stage was measured for 15 seconds, the other combustion stages were measured in the intervals of 30 seconds. Temperature changes (°C) were measured by a thermometer, while the smoke density generated during the combustion was measured from a device which showed the light intensity as a unit with the photocell sensor (Atar et al. 2010a).

During the combustion test, temperature (°C), illuminance (lux), weight loss (%), total time of combustion, and demolition time (seconds) values were measured in CWF, SC and EC stages.

Statistical analyses were conducted using SPSS 20.0 (2011) software program. Multiple variance analyses (UNIVARIATE) were applied with the level of confidence of 99%, differences between groups were compared using the Duncan test.

RESULTS AND DISCUSSION

Combustion temperature and illuminance values

The results of the analyses of the relationship between wood species, impregnation material and varnish type on combustion temperature and illuminance values of CWF, SC, and EC stages are given in Tab. 2 and Tab. 3.

Tab. 2: Results of variance analysis of combustion temperatures during combustion stages.

Factor	Temperature values at CWF					Temperature values at SC					Temperature values at EC				
	Sum of squares	Df	Mean square	F.Value	P	Sum of squares	Df	Mean square	F.V.	P	Sum of squares	Df	Mean square	F.Value	P
WS (A)	147.610	1	147.610	3.778	.060*	11549.436	1	11549.436	164.121	.000	74142.608	1	74142.608	380.050	.000
IM (B)	5159.438	2	2579.719	66.022	.000	8568.750	2	4284.375	60.882	.000	32412.000	2	16206.000	83.071	.000
VT (C)	165.562	2	82.781	2.119	.135*	4344.938	2	2172.469	30.871	.000	3249.187	2	1624.594	8.328	.001
A+B	1764.188	2	882.094	22.575	.000	13019.250	2	6509.625	92.504	.000	10967.250	2	5483.625	28.109	.000
A+C	174.562	2	87.281	2.234	.122*	41.812	2	20.906	.297	.745*	15601.687	2	7800.844	39.987	.000

B+C	5617.500	4	1404.375	35.942	.000	5379.000	4	1344.750	19.109	.000	10273.313	4	2568.328	13.165	.000
A+B+C	6106.875	4	1526.719	39.073	.000	2846.625	4	711.656	10.113	.000	22308.563	4	5577.141	28.588	.000
Error	1406.653	36	39.074			2533.375	36	70.372			7023.111	36	195.086		
Total	11343017.372	54				15257431.398	54				7021804.478	54			
Error	20542.387	53				48283.186	53				175977.720	53			

WS: wood species; IM: impregnation materials; VT: varnish types; P: α ≤ 0.05 *: insignificant

According to these findings, interactions between temperature values of the CWF stages, except WS and VT, interactions between the double interaction of WS+VT, and interactions between temperature values of the SC stage, except double interaction of WS+VT all interactions were found to be significant.

Tab. 3: Results of variance analysis of illuminance values during combustion stages.

Factor	Illuminance values at CWF					Illuminance values at SC					Illuminance values at EC				
	Sum of squares	Df	Mean square	F.Value	P	Sum of squares	Df	Mean square	F.V.	P	Sum of squares	Df	Mean square	F.Value	P
WS (A)	5002.594	1	5002.594	1954.881	.000	16250.531	1	16250.531	688.809	.000	6885.602	1	6885.602	3378.285	.000
IM (B)	83.250	2	41.625	16.266	.000	3600.187	2	1800.094	76.300	.000	182.437	2	91.219	44.755	.000
VT (C)	153.562	2	76.781	30.004	.000	2269.312	2	1134.656	48.095	.000	3.563	2	1.781	.874	.426*
A+B	110.250	2	55.125	21.541	.000	753.187	2	376.594	15.963	.000	265.687	2	132.844	65.177	.000
A+C	489.938	2	244.969	95.727	.000	2201.063	2	1100.531	46.648	.000	366.937	2	183.469	90.015	.000
B+C	311.625	4	77.906	30.444	.000	348.000	4	87.000	3.688	.013	149.438	4	37.359	18.330	.000
A+B+C	93.375	4	23.344	9.122	.000	2293.875	4	573.469	24.308	.000	22.312	4	5.578	2.737	.044
Error	92.125	36	2.559			849.319	36	23.592			73.375	36	2.038		
Total	5864682.813	54				5165562.739	54				5937671.358	54			
Error	6336.719	53				28565.475	53				7949.352	53			

WS: wood species; IM: impregnation materials; VT:varnish types; P: α ≤ 0.05 *: insignificant

All interactions between illuminance values of EC stage except VT were found to be significant. The interactions of wood species, impregnation material, and varnish type, as well as the mean values of temperature and illuminance on combustion stages are as shown in Figs. 2 and 3.

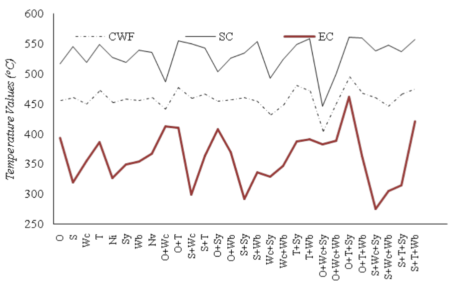

Fig. 2: The effect of impregnation materials and varnish types, on wood species' temperature values during combustion stages.

Combustion values of EC stage increased by 9-18% with impregnation material, decreased by 4-5% with varnish type. When compared with the control samples, Tanalith-E resulted in temperature increases in the combustion stages by 4, 4 and 18%, respectively. In a similar study, it was determined that copper azole compounds worsened the combustion properties of wood (Can et al. 2017). The mean combustion temperature values were highest in the O+T+Sy samples and lowest in CWF and SC stage in O + Wc +Sy samples.

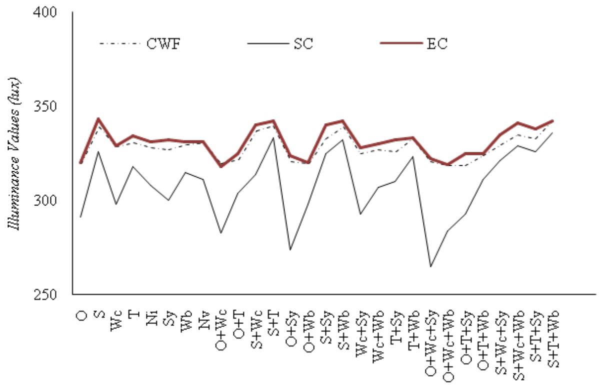

Fig. 3: The effect of impregnation materials and varnish types, on wood species' illuminance values during combustion stages.

The mean illuminance value in combustion was highest in the S+T+Wb samples in the CWF and SC stages. Wolmanit-CB reduced the temperature and illuminance values in all combustion stages. Due to presence of the boric acid in this component, boric acid may suppress the flame during combustion (Levan 1984, Wang and Winandy 2004).

Weight loss and combustion times

The results of the analysis of the effect of wood species, impregnation material and varnish type on demolition time, total combustion time, and weight loss values during combustion are given in Tab. 4.

Tab. 4: Results of variance analysis of combustion times and weight loss during combustion stages.

Factor	Demolition time (DT)					Total time of combustion (TC)					Weight loss (WL) (%)				
	Sum of squares	Df	Mean square	F.Value	P	Sum of squares	Df	Mean square	F.V.	P	Sum of squares	Df	Mean square	F.Value	P
WS (A)	222343.275	1	222343.275	325.463	.000	55662528.021	1	55662528.021	745.332	.000	8.128	1	8.128	30.986	.000
IM (B)	82743.750	2	41371.875	60.560	.000	17996981.250	2	8998490.625	120.492	.000	38.472	2	19.236	73.331	.000
VT (C)	24342.188	2	12171.094	17.816	.000	5977973.438	2	2988986.719	40.023	.000	2.614	2	1.307	4.983	.012
A+B	82575.000	2	41287.500	60.436	.000	5779481.250	2	2889740.625	38.694	.000	59.637	2	29.819	113.673	.000
A+C	104329.688	2	52164.844	76.358	.000	2986626.563	2	1493313.281	19.996	.000	5.561	2	2.781	10.601	.000
B+C	13275.000	4	3318.750	4.858	.003	3007556.250	4	751889.063	10.068	.000	10.844	4	2.711	10.335	.000
A+B+C	24750.000	4	6187.500	9.057	.000	546590.625	4	136647.656	1.830	.144*	10.358	4	2.589	9.871	.000
Error	24593.750	36	683.160			2688534.028	36	74681.501			9.444	36	.262		
Total	15890990.150	54				645975235.945	54				464867.389	54			
Error	578952.650	53				94646271.424	53				145.059	53			

WS: wood species; IM: impregnation materials; VT: varnish types; P: $\alpha \leq 0.05$ *: insignificant

According to these findings, all interactions were significant except triple interaction of total time of combustion. According to interactions of wood species, impregnation material and varnish type, the mean values of weight loss, total combustion time, and demolition time values on combustion are as shown in Figs. 4 and 5.

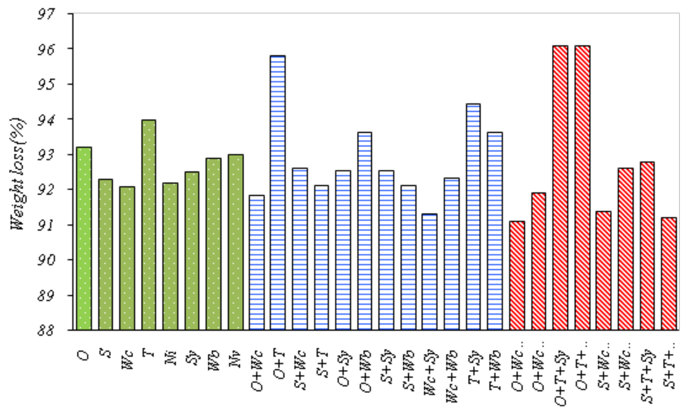

Fig. 4: The effect of impregnation materials and varnish types, on wood species' s weight loss during combustion.

The highest weight loss from combustion was in O+T+Sy and O+T+Wb samples, and the lowest in O+Wc+Sy samples.

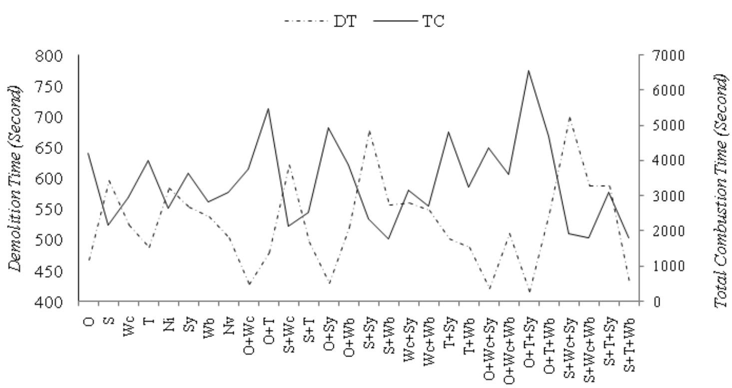

Fig. 5: The effect of impregnation materials and varnish types, on wood species' s demolotion time and total combustion times.

The demolition time in combustion period of oriental beech is shorter and total combustion time is higher than Scots pine (Atar et al. 2010b). The excessive amount of hemicellulose in the composition of Oriental beech may be because of early demolition (Yang et al. 2007, Rowell and Dietenberger 2013). Synthetic varnish decreases combustion temperatures and increases combustion time (Fidan et al. 2016, Yasar et al. 2017b).

Compared with the control samples, impregnation materials decreased the demolition time by 10 to 15% and increased combustion time by 12 to 51%. The highest demolition time during combustion was in S+Wc+Sy samples and lowest in O+Wc+Sy samples. The highest total time of combustion was seen in the O+T+Sy samples and lowest in S+Wb samples.

CONCLUSIONS

The aim of this paper was to obtain combustion properties of Scots pine (*Pinus sylvestris* L.) and Oriental beech wood (*Fagus orientalis* L.) during combustion stages. For this purpose, combustion temperatures, illuminance values, total time of combustion, weight loss, and demolition time were measured on wood samples which were impregnated with Tanalith-E and Wolmanit-CB and were varnished.

Wood type, impregnation material, and varnish type affect the combustion properties of wood materials in different ways. The Oriental beech's self-combustion period is too short to reach high temperatures, except during ember combustion. The temperature and illuminance values were decreased with Wolmanit-CB and increased with Tanalith-E. The varnishes decreased combustion temperature and illuminance values.

Triple interaction of Oriental beech, Tanalith-E, and Synthetic varnish resulted in the highest temperature values in all combustion stages.

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