Combustion Properties of Oriental Beech Wood (*Fagus Orientalis* L.) Which were Left to Seasonal Conditions

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Abstract— In addition to its positive features such as being a renewable, durable and lightweight material, wood also has drawbacks such as burning and deformations in outdoor conditions. This study was carried out to determine the changes in the combustion characteristics and weight loss of the Oriental beech *(Fagus orientalis* Lipsky) wood exposed to seasonal effects on outdoor.

For this purpose, after Oriental beech samples were prepared according to ASTM-E 160-50 and they were impregnated with tanalith-E (T) and wolmanit-CB (WCB) according to ASTM-D 1413-76, synthetic (Syn) and water-based (Wb) varnish were applied according to ASTM-D 3023. At the beginning of the seasons (summer, autumn, winter, spring), the samples were left to outdoor and then were subjected to combustion tests at the end of the season to determine temperature values, time of collapse (TC), total time of combustion (TTC) and weight loss (WL) during the combustion (FS, SC, EC stage).

The effect of the seasons was the most decisive factor in the experiments. After combustion weight loss was the highest in autumn (94.9%) and lowest in summer (92.1%). Summer samples showed the highest temperatures values in FS, SC and cooled rapidly at the EC stage. The opposite values were obtained during the spring and winter seasons. Impregnated materials increased the weight loss on combustion.

Keywords— **Combustion, Wood, Impregnation, Seasonal conditions, Outdoor**

I. Introduction

Oriental beech (*Fagus orientalis* Lipsky) forests reach from the Balkans to Istanbul, then goes down to the Aegean Region and at the same time from here to the Caucasus and the Crimea along the Eastern Black Sea [1]. Beech tree constitutes of 9% ratio of Turkey forest asset, it is second in broad-leaved trees [2]. Beech wood is used as furniture, pallet, parquet, wood-based panels (chipboard, fibreboard, particleboard), toys and for wood fuel [3].

Treatment with chemical and natural preservatives, coating by surface materials, thermal applications and modifications can be used to decrease the weathering effects on outdoor wood applications [4-7].

Cellulose, hemicellulose and lignin, which form the core of wood, show different behaviors during outdoor conditions and combustion. For example, lignin has a lower resistance to hemicellulose and cellulose than it has to cellulose in photodegradation [8, 9]. The thermal degradations of wood follow between at about 200°C and 260°C with degradation of hemicelluloses followed by between at about 240°C and 350°C with degradation of cellulose and between at about 280°C and 500°C with lignin [10]. Wood combustion starts with moisture loss and followed by hemicellulose, cellulose and lignin degradation [11,12].

Boron, borax, chloride, phosphoric acid, nitrogen, zinc chloride, melamine, ammonium sulfate-chloride and combination of these elements are used as today's most widely flame retardants for wood [13-16].

The effect of commercial wood preservatives (Vacsol aqua, imersol aqua, adolit BQ1, wolmanit-CB, tanalith C3310, ammonium pentaborate, borax decahydrate,disodium octaborate tetrahydrate, ammonium tetrafluoroborate and sodium tetrafluoroborate) on 4% concentration was evaluated by thermogravimetry, differential thermogravimetry and differential thermal analysis of scots pine. The highest amount of char content was observed in the combustion stage on wolmanit-CB and the other containing boric oxide wood preservatives [17].

In the present work the effects of seasonal conditions, impregnation materials and varnishes on the combustion characteristics of the beech wood will be examined.

II. Materials and Methods

A. *Materials*

The Oriental beech (Fagus orientalis Lipsky) wood selected from knotless, normally grown, in Eastern Black Sea Region of Turkey not from reaction wood and fungal decay wood obtained in accordance with the principles specified in ASTM D–358 [18].

The impregnation materials used in this study are Tanalith-E and Wolmanit-CB. Tanalith-E, and Wolmanit-CB was supplied respectively from Hemel A.Ş. and Ramsan-Emsan Korusan. Tanalith-E is a material which is used as water-based containing mixture of copper carbonate, tebuconazole, propiconazole, 2-aminoethanol, boric acid, organic acid and polyethyleneamine [19]. Wolmanit-CB contains copper sulphate, potassium bichromate and boric acid [20]. Studies have shown that Wolmanit-CB is a late-burning material but cannot withstand to fire for a long-term [21, 22].

Synthetic and water-based varnishes were used in the study. In a study where the air quality was measured in the houses, the amounts of gas were observed in the closed furniture at between 15-25% more than the room cavities [23]. The advantage of water-based varnish is that it does not emit harmful volatile gases while the solvent is evaporating [24, 25].

B. *Methods*

The rough cut samples were cut from the sapwood parts of beech lumber with dimensions of 20×20×500 mm. Wood samples were held in a climatized room until their weights didn't change and reached to 12% moisture content. Beech samples were cut in dimensions of 13 x 13 x 76 mm with (radial x tangent x length) according to ASTM-E 160-50 principles [26]. According to the process shown in Table I. for each test period a total of 24 test specimens were prepared in three replications [24].

TABLE I.

QUANTITY OF TEST PIECES PREPARED IN THE RESEARCH

Seasonal Groups	Impregnation Materials	Varnish Types	Number
Summer (S) Autumn (Au) Winter (W) Spring (Sp) Annual (A)	Wolmanit-CB (WCB) Tanalith-E (T)	Water-based varnish (Wb) Synthetic varnish (Syn)	24x3 = 72 24x3 = 72 24x3 = 72 24x3 = 72 24x3 = 72

The test samples were impregnated by vacuum-pressure method according to ASTM-D 1413-76 [27]. Concentration of Wolmanit-CB was 4% and Tanalith-E was 2,4%. The pH values of impregnated materials did not show any significant change after impregnation. The mean pH value measured in Wolmanit-CB is 4,3 and tanalit-E is 9,9. The impregnated materials were left in a room where airflow was provided for 20 days until they reached moisture content of 12% at constant weight. The application of the varnishes was conducted following the manufactures instructions according to ASTM-D 3023 principals [28]. The amount of solid matter in the synthetic varnish is 47% and in the water based varnish is 33% [29]. The samples applied with varnish were left to outdoor conditions according to ASTM G7-05 at the beginning of the seasons and were kept in the conditioning room for 20 days at the end of the seasons [30].

Combustion was carried out in three stages according to ASTM-E 160-50 principles. After combustion was carried out for three minutes with flame source stage (FS), the flame source was closed and self combustion stage (SC) and ember combustion stage (EC) occurred. At the end of research temperature values of combustion stages (FS, SC, EC), time of collapse (TC), total time of combustion (TTC) and weight loss (WL) were obtained.

The statistical evaluation of the results was analyzed with SPSS 20.0 statistical package software. The results statistically tested with the one-way analysis of variance. Mean and standard deviation values were evaluated statistically.

III. Results and Discussion

The variance analysis of seasonal conditions, impregnation materials and varnishes types on combustion temperatures, time of collapse, total time of combustion and weight loss are presented in Table II. and Table III.

TABLE II.
THE RESULT OF VARIANCE ANALYSIS OF COMBUSTION TEMPERATURES

Source	Temperature Value of FS				
	F.D.	S.S.	S.M.	F.V.	P.V.
sg	4	43008,411	10752,103	11,947	0,000
im	2	6036,239	3018,119	3,353	0,039
vt	2	126,973	63,486	0,071	*0,932
sg*im	8	7816,565	977,071	1,086	*0,380
sg*vt	8	13973,310	1746,664	1,941	*0,063
im*vt	4	7483,343	1870,836	2,079	0,090
sg*im*vt	16	43766,292	2735,393	3,039	0,000
Error	90	81000,346	900,004		
Total	134	203211,479			
Temperature Value of SC					
sg	4	52236,490	13059,122	20,643	0,000
im	2	10205,522	5102,761	8,066	0,001
vt	2	10774,778	5387,389	8,516	0,000
sg*im	8	33550,271	4193,784	6,629	0,000
sg*vt	8	10603,037	1325,380	2,095	*0,044
im*vt	4	10502,941	2625,735	4,151	0,004
sg*im*vt	16	21987,688	1374,231	2,172	*0,011
Error	90	56936,750	632,631		
Total	134	206797,477			
Temperature Value of EC					
sg	4	111754,567	27938,642	11,344	0,000
im	2	65499,081	32749,541	13,297	0,000
vt	2	24035,501	12017,750	4,879	0,010
sg*im	8	24089,406	3011,176	1,223	*0,295
sg*vt	8	46514,579	5814,322	2,361	0,024
im*vt	4	69298,277	17324,569	7,034	0,000
sg*im*vt	16	40076,299	2504,769	1,017	*0,447
Error	90	221662,886	2462,921		
Total	134	602930,596			

sg: seosonal groups, im: impregnation materials, vt: varnish types

According to this; at interactions on temperature values of FS stage, all interactions were found significant except varnish and double interaction of sc+im, sc+vt and im+vt, At interactions on temperature values of SC stage, all interactions were found significant except double interaction of sc+vt. At interactions on temperature values of EC stage, all interactions were found significant (P<0.05) except double interaction of sc+im and triple interaction.

TABLE III.
THE RESULT OF VARIANCE ANALYSIS OF COMBUSTION TIMES AND WEIGHT LOSS

TC					
sg	4	151930,948	37982,737	6,886	0,000
im	2	24148,567	12074,284	2,189	*0,118
vt	2	32132,595	16066,298	2,913	*0,059
sg*im	8	101519,540	12689,942	2,301	0,027
sg*vt	8	46174,285	5771,786	1,046	*0,408
im*vt	4	112951,163	28237,791	5,119	0,001
sg*im*vt	16	151804,496	9487,781	1,720	*0,057
Error	90	496421,476	5515,794		
Total	134	1117083,069			
TTC					
sg	4	203930109,5	50982527,36	77,021	0,000
im	2	23398851,56	11699425,36	17,675	0,000
vt	2	3178636,993	11699425,78	2,401	*0,096
sg*im	8	47191704,05	1589318,496	8,912	0,000
sg*vt	8	5266456,770	5898963,006	0,995	*0,446
im*vt	4	4088727,690	658307,096	1,544	*0,196
sg*im*vt	16	3135860,336	1022181,923	0,296	*0,996
Error	90	59573543,87	195991,271		
Total	134	349763890,7	661928,265		
WL					
sg	4	114,507	28,627	31,643	0,000
im	2	42,305	21,153	23,381	0,000
vt	2	13,857	6,929	7,659	0,001
sg*im	8	212,547	26,568	29,367	0,000
sg*vt	8	16,561	2,070	2,288	0,028
im*vt	4	29,741	7,435	8,219	0,000
sg*im*vt	16	12,586	0,787	0,869	*0,605
Error	90	81,422	0,905		
Total	134	523,526			

sg: seosonal groups, im: impregnation materials, vt: varnish types

At interactions on TC, all interactions were found significant except im, vt, double interaction of sc+vt and triple interaction. At interactions on TTC all interactions were found significant (P<0.05) except vt, double interaction of sc+vt, im+vt and triple interaction.

The mean values of combustion temperatures, time of collapse, total time of combustion and weight loss are presented in Table IV. and the graphic belong to these values are given in Figure 1., Figure 2. and Figure 3.

TABLE IV.
MEAN VALUES OF THE COMBUSTION TEMPERATURES, COMBUSTION TIMES AND WEIGHT LOSS

Factors		Combustion Temperatures (^{o}C)			Combustion Times (sec)		WL (%)
		FS	SC	EC	TC	TTC	
sg	S	475,6	565,4	343,9	470	2203,3	92,1
	Au	471,7	527,6	403,8	452,8	5973,3	94,9
	W	446,6	523,3	410,4	479,7	3514,2	93,9
	Sp	426,4	508,7	429,	386,7	3538,1	94
	A	456,3	516,1	393,1	468,3	4210,6	93,2
	Mean	455,3	528,2	396	451,5	3887,9	93,6
	S_x	5,774	4,841	9,551	14,293	156,6	0,183
im	WCB	449,1	533	408,8	453,5	4234,5	94,1
	T	464,6	535,6	414,6	434,2	4126,8	94
	Nimp	452,2	516	365,3	466,8	3302,4	92,8
	Mean	455,2	528,2	396,2	451,5	3887,9	93,6
	S_x	4,472	3,749	7,398	11,071	121,283	0,142
vt	Syn	455,5	517,4	410,8	447,5	4104,7	93,2
	Wb	456,4	539,	378,6	472,1	3786,9	93,9
	Nvar	454	527,9	399,3	434,9	3772,1	93,7
	Mean	455,3	528,1	396,2	451,5	3887,9	93,6
	S_x	4,472	3,749	7,398	11,071	121,283	0,142

Nimp: Non impregnated Nvar: Non varnished, Sx: Standard deviation

The mean combustion values in FS stage determined highest in summer (475,6 ^{o}C) and lowest in spring samples (426,4 ^{o}C). In SC stage showed highest values in summer (565,4 ^{o}C) and lowest in annual and non-impregnated samples (516 ^{o}C). EC stage showed highest values in spring (429 ^{o}C) and lowest in summer samples (343,9 ^{o}C). Time of collapse of samples showed highest values in winter and lowest in spring samples. Total time of combustion and weight loss showed highest values in autumn and lowest in summer samples.

Mean values of interactions of between seasons, impregnation materials and varnishes type on combustion temperatures, combustion times and weight loss values are presented in Table V.

TABLE V.
MEAN VALUES OF INTERACTIONS OF BETWEEN SEASONS, IMPREGNATION MATERIALS AND VARNISHES TYPE ON COMBUSTION VALUES

Factors			FS	SC	EC	TC	TTC	WL
S	WCB	Syn	484	553	382	520	1985	90
		Wb	504	587	304	465	1950	92
		Nvar	429	536	364	445	1745	91
	T	Syn	496	574	427	515	2835	94
		Wb	490	594	303	465	2685	94
		Nvar	488	574	371	470	2845	93
	Ni	Syn	490	576	378	440	2075	91
		Wb	449	574	261	505	1925	93
Au	WCB	Syn	435	538	358	552	7910	97
		Wb	454	519	450	394	7415	97
		Nvar	517	583	395	481	7486	97
	T	Syn	454	499	451	338	5963	95
		Wb	510	556	378	507	4767	93
		Nvar	473	514	389	451	5408	93
	Ni	Syn	476	508	470	394	4842	93
		Wb	465	521	362	507	5243	95
W	WCB	Syn	457	528	373	551	3857	94
		Wb	373	515	473	433	3713	94
		Nvar	466	567	460	427	3810	96
	T	Syn	487	540	442	440	3657	93
		Wb	447	532	462	413	3446	93
		Nvar	429	494	425	413	3922	94
	Ni	Syn	435	482	407	447	2962	92
		Wb	479	542	305	640	3768	95
Sp	WCB	Syn	426	516	397	490	4089	96
		Wb	436	545	437	423	3762	95
		Nvar	430	550	502	336	4493	96
	T	Syn	422	472	464	303	3504	92
		Wb	423	519	443	383	3151	92
		Nvar	420	505	435	376	3315	94
	Ni	Syn	406	466	393	430	3124	92
		Wb	444	509	392	383	3326	94
A	WCB	Syn	404	445	382	421	4360	91
		Wb	450	499	389	511	3618	92
		Nvar	470	515	466	353	3325	92
	T	Syn	495	560	461	417	6543	96
		Wb	468	559	364	545	4698	96
		Nvar	468	542	404	477	5163	95
	Ni	Syn	467	503	378	455	3865	90
		Wb	452	519	356	507	3336	93

FC stage came out highest in Au+WCB and lowest in W+WCB+Wb, SC stage came out highest in S+T+Wb and lowest in A+WCB+Syn, EC stage came out highest in Sp+WCB and lowest in S+Wb, TC came out highest in W+Wb and lowest in Sp+T+Syn, TTC came out highest in Au+WCB+Syn and lowest in S+WCB, WL came out highest in Au+WCB+Syn and lowest in S+WCB+Syn.

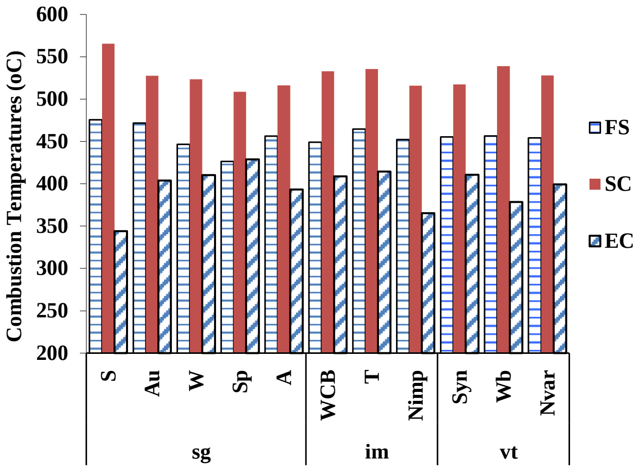

Figure 1. Mean values of the combustion temperatures

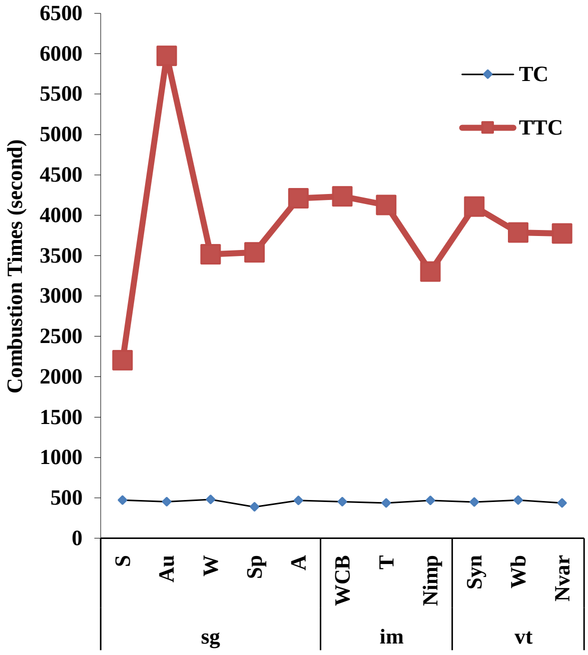

Figure 2. Mean values of the combustion times

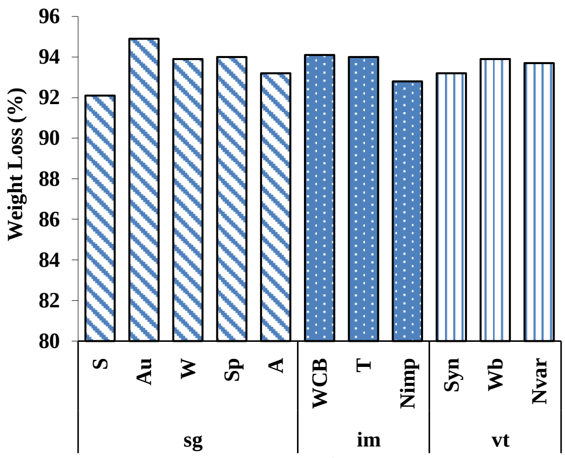

Figure 3. Mean values of the weight loss

IV. Conclusions

this study investigated weight loss, combustion temperatures, collapse time and total combustion time, in combustion stages of Oriental beech wood kept in outdoor. As a result, impregnation material, varnish type and especially seasonal effects, has affected the combustion properties of wood materials.

Seasonal changes showed minimum and maximum values in all combustion parameters. Wolmanit-CB reduced the temperature values, may cause boric acid contains in its composition [31, 32]. The lowest time of collapse in combustion value was measured in spring and highest in winter season. Total combustion time was increased about 54% in autumn samples and reduced 43% in summer samples. Weight loss in combustion values is similar with this result. Many studies have shown that lignin is affected by the sun-light. Decrease in amount of lignin may be the cause of these results [33].

Acknowledgment

This research has been constituted from some sections of doctoral thesis of Şadiye YAŞAR prepared under the supervision of Prof. Dr. Musa ATAR in Gazi University Institute of science and technology in April 2015.

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