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Combustion properties of impregnated and heat-treated wood material

Emprenye edilmiş ve ısıl işlem uygulanmış ahşap malzemenin yanma özellikleri

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Combustion Properties of Impregnated and Heat-Treated Wood Material

Research Article / Araştırma Makalesi

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ABSTRACT

The use of heat-treated wood material and eco-friendly impregnation chemicals are steadily increasing in the woodworking industry over the last decades. In this study, the effects of applications of impregnation and heat treatment on combustion properties of Hornbeam (*Carpinus betulus* L.) wood were investigated. The test specimens were impregnated with Imersol-aqua (Ia) and Timbercare-aqua (Ta) impregnation material according to ASTM D 1413-76 standards. Impregnated specimens were subjected to heat treatment at 150, 170 and 190 °C for 2 h. The temperature of flame source combustion, the temperature of without flame source combustion and varying light intensities (Lux) depending on the smoke production in these combustion stages were determined according to ASTM E 160-50. According to the test results, the highest combustion temperature of flame source combustion was determined in unimpregnated and heat-treated samples at 190 °C, while the highest combustion temperature of without flame source combustion was determined in impregnated with Ta and heat-treated samples at 170 °C. The highest light density in flame source combustion phase was determined in unimpregnated and heat-treated samples at 190°C, while in without flame source combustion was in unimpregnated and heat-treated samples at 170°C. As a result, as the heat treatment temperature increase, the combustion temperature increased and the smoke density decreased. In addition to impregnation materials increased the smoke density while reduced the combustion temperatures of test specimens.

Keywords: Heat treatment, imersol-aqua, timbercare-aqua, combustion, smoke production.

Emprenye Edilmiş ve Isıl İşlem Uygulanmış Ahşap Malzemenin Yanma Özellikleri

ÖZ

Son yıllarda ağaç işleri endüstrisinde ısıl işlem uygulanmış ağaç malzeme ve çevre dostu emprenye kimyasallarının kullanımı giderek artmaktadır. Bu çalışmada, emprenye ve ısıl işlem uygulamalarının Gürgen (*Carpinus betulus* L.) ağacının yanma özelliklerine etkileri incelenmiştir. Deney örnekleri, Imersol-aqua (Ia) ve Timbercare-aqua (Ta) emprenye maddeleri ile ASTM D 1413-76 standardına göre emprenye edilmişlerdir. Emprenyeli örneklere 150, 170 ve 190 °C'de 2 saat ısıl işlem uygulanmıştır. Çalışmada alev kaynaklı yanma sıcaklığı, alev kaynaksız yanma sıcaklığı ve bu yanma aşamalarındaki duman üretimine bağlı olarak değişen ışık yoğunlukları (Lux) ASTM E 160-50 standardına göre belirlenmiştir. Test sonuçlarına göre en yüksek alev kaynaklı yanma sıcaklığı, emprenye edilmemiş ve 190 °C'de ısıl işlem uygulanan örneklerde, en yüksek alev kaynaksız yanma sıcaklığı ise Ta ile emprenye edilen ve 170 °C'de ısıl işlem uygulanan örneklerde belirlenmiştir. Alev kaynaklı yanma aşamasında en yüksek ışık yoğunluğu emprenye edilmemiş ve 190°C'de ısıl işlem uygulanan örneklerde belirlenirken, alev kaynaksız yanma aşamasındaki en yüksek ışık yoğunluğu ise emprenye edilmemiş ve 170°C'de ısıl işlem uygulanan örneklerde belirlenmiştir. Sonuç olarak ısıl işlem sıcaklığın artmasıyla yanma sıcaklığı artarken, duman yoğunluğu azalmıştır. Ayrıca emprenye maddeleri test örneklerinin duman yoğunluğunu arttırırken, yanma sıcaklığını azaltmıştır.

Anahtar Kelimeler: Isıl işlem, imersol-aqua, timbercare-aqua, yanma, duman üretimi

1. INTRODUCTION

The wood and wood-based building sector is developing in recent years, in the world. Wood is a very suitable material for construction, because of its a number of advantages not found compared to other building materyal [1]. Wood is renewable, easily workable and eco-friendly material that is available globally and comparable in strength to modern structural materials. For these reasons it has been widely used in interior architecture decorations for many years[2]. Despite all these positive features, the wood material has some undesirable characteristics, one of the most important of them, it has easy burning feature [3]. In order to reduce the burning properties and to improve safety of wood, it is treated with some fire-retardant chemical substances[4]. Combustion properties of wood material can not be completely prevented, but it is possible to make it fire resistant with some chemicals[5].

Atar et al. [6] studied the effects of varnishing after impregnation with boron compounds on the combustion

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properties of Scotch pine (*Pinus sylvestris* L.) wood. They reported that impregnation chemicals decreased while varnishes increased the combustion temperature wood. In another study, Keskin et al. [7] studied the effects of impregnation with borax, boric acid, imersol-aqua and timbercare-aqua on combustion properties of the laminated wood, manufactured from Oriental beech and poplar veneers bonded with two different adhesive. As a results of study boron compounds showed a decreasing impact on combustion properties of the laminated wood materials. In a similar study Fidan et al. [8] investigated the effect of impregnation materials and synthetic or water-based varnish on the combustion properties of wood (*Cedrus libani* A. Rich.) material. Yaşar et al. [9] determined the combustion characteristic of impregnated spruce (*Picea orientalis* L.) wood.

In order to improve the properties of wood materials, significant studies have been carried out in recent years, one of which is heat treatment. Heat treatment is an effective alternative method for improving wood properties with no use of chemical materials [10]. During heat-treatment the properties of wood are changed. Many researchers have studied effects of combustion properties of wood materials, hovewer, knowledge about the combustion properties of heat-treated wood is very limited. It may be important to determine the burning properties of heat-treated wood material, due to the increased use of heat-treated wood materials.

Müllerová [11] studied that fire tests of heat-treated spruce and pine wood were determined according to ISO 5660. Heat-treated spruce wood reduce the smoke released comparing to control sample. Heat-treated pine shows increasing effect on smoke release. In addition to, heat-treated soft wood has decreased ignition time and heat release when burning. Percin [12] investigated the effects of borax and boric acid on the combustion properties of heat-treated and laminated veneer lumber manufactured from Anatolian black pine wood. He reported that boron compounds showed fire retarding effect on combustion properties of wood. Also heat treatment showed decreasing effect on combustion temperature of wood except for TFS phase and weight loss rate. Gašparík et al. [13] determined flammability properties of heat-treated and fire-retardant treated oak wood (*Quercus robur* L.) at 160, 180 and 210 °C. As result they reported that heat treatment did not show clear effect on combustion properties of wood. Weight loss and burning rate decreased with heat treatment temperature and as the heat temperature increased without fire retardant treatment, time to reach the maximum burning rate decreased.

Volatile and flammable gases during the burning process can be effect on combustion properties and spread of flame of wood material [14,15]. Thermally conditions effect on flame and combustion properties of wood [16]. During the heat treatment process volatile organic compounds releases and they increasing with heat treatment temperature [17], which are explained by the thermal degradation and oxidation of main chemical compounds in wood material and closely releated to the combustion properties of wood [18].

The use of heat-treated wood materials for interior and exterior elements in the woodworking industry have been increased in recent years [19]. Also environmentally friendly wood preservative chemicals play an important role in wood indutry. Therefore, this study was performed to determine the impacts of heat treatment process after impregnation with Imersol-aqua and Timbercare-aqua on the combustion properties of the Hornbeam (*Carpinus betulus* L.) wood.

2. MATERIAL and METHOD

2.1. Materials

2.1.1. Wood material

The Hornbeam (*Carpinus betulus* L.) wood specimens from the Kütahya region in Turkey were used in this study. The moisture content of the boards ranged from 10-14% and density was 0.776 g/cm^3. Hornbeam wood is commonly used in the forest products and furniture industries in Turkey. Wood materials randomly selected from timber supplier in Simav- Kütahya. The oversized boards were kept in same normal environmental conditions for approximately two months.

2.1.2. Impregnation Material

Impregnation process was performed with two different wood modifiers. Commercially produced Imersol-aqua (Ia) and Timbercare-aqua (Ta) were used as impregnation material in this study was supplied from Hemel company in Istanbul, Turkey. Ia and Ta are eco-friendly, nonflammable, odorless, fluent, water-based, completely soluble in water, non-corrosive material and they are available as a ready-to-use solution. The pH and density value of both chemicals are 7 and 1.03 g/cm^3, recpectively [20,21].

2.2. Method

2.2.1. Preparation of test samples and impregnation

The test and control samples were cut from the sapwood parts of air-dried Hornbeam (*Carpinus betulus* L.) wood with a dimension of 500 × 17 × 17 mm in the longitudinal, radial and tangential directions according to TS 2470 [22]. This stick samples were conditioned at 20˚C ± 2˚C temperature and 65% ± 3% relative humidity for four weeks. Then the samples were cut and planed into the size 13 × 13 × 76 mm for impregnation process. In the tests, totally 864 (3x4x3x24) samples were combusted (24 test samples in each group, 2 different impregnation material and control group, 3 different heat treatment temperature and unheated group and 3 groups in each test). Test samples with initial equilibrium moisture content around 12% were impregnated with solutions before heat treatment. The test samples were impregnated with Ia by dipping method for 24 hours and Ta by brushing method according to ASTM D-1413-99 [23]. The impregnation process with brush was applied twice at intervals of 5 hours.

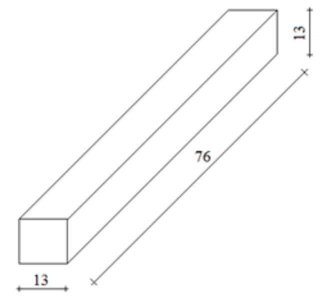

Figure 1. Combustion test sample and dimensions

2.2.2. Heat treatment

Test samples were subjected to heat treatment in a thermal oven under the protection of hot steam. Three final temperature 150, 170 and 190°C were chosen for the wood modification in this study. Heat treatment was applied in three phase. During the all heat treatment, hot steam was sprayed into the oven with 1 bar and time of 5 sec. at intervals of 200 sec. In the first phase, temperature of oven was raised to 100 °C for 6 hours and then the temperature was raised to 130 °C for 12 hours. In the second phase, the temperature raised from 130 °C to 150, 170, and 190 °C for 6 hours using steam. In this phase, temperature remains constant for 2 hours. In the final conditioning phase, the temperature was reduced to 25 °C for 12 h (Total treatment was 38 h). After heat treatment, the samples were conditioned at temperature of 20 ± 2°C temperature and a relative humidity of 65± 3% until reaching an equilibrium moisture content. Figure 2 shows heat treatment process.

2.2.3. Combustion test

In this study, to investigate the combustion properites of wood, the experiments were done in combustion test device according to ASTM E 160-50 [24]. Detailed information about the experiments and test device are given in this standard. The weights of the test samples were determined before each combustion test. The combustion tests were carried out subsequently according to standard. The flame source combustion (FSC) was continued for 180 s. After the flame source turned off and without flame source combustion (WFSC) was carried out. Temperatures in during combustion test were determined in °C buring column by a thermometer and the light density (Lux) was recorded by photocell detector. The light density changes depending on the smoke production and light density decreases with increasing smoke production. The combustion tests were carried out in combustion laboratory of Department of Furniture and Decoration Education, Faculty of Technical Education, Gazi University. The combustion test device shown in Figure 3 [9].

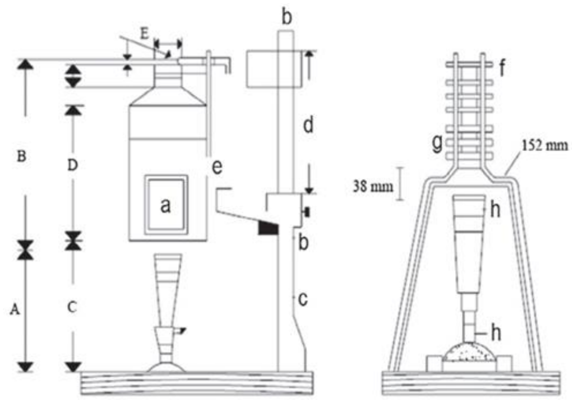

Figure 3. Combustion test device [9].

(a: mica glass, b: end of slide, c: flame burner guide, d: slide, e: millivoltmeter inlet, f: test specimens g. wire cage, h: flame burner)

2.2.4. Statistical analyses

In data analysis, in order to determine the effects of the impregnation material and heat treatment temperature and their mutual interactions on combustion properties, multiple analyses of variation (MANOVA) was used by MSTAT-C software package. If there is a significant difference between factor and their mutual interactions, Least Significant Difference (LSD) test was used to determine meaningful difference among the groups.

3. RESULT AND DISCUSSION

Table 1 shows the changes in air-dried density values of impregnated and then heat-treated samples. According to these results, after impregnation process the density values showed a small increase in the each test. In addition higher heat treatment temperature decreased density value of test samples. Impregnation with Ia and Ta solutions before heat treatment resulted in higher density values compared with the unimpregnated samples. The highest density was determined in the impregnated with Ta and unheated samples, while lowest in unimpregnated and at 190 °C heat-treated specimens.

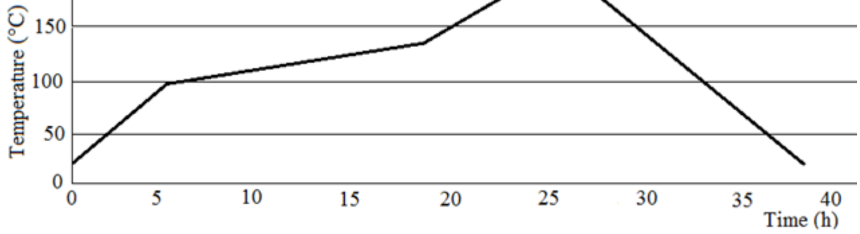

Figure 2. Heat treatment schedule (at 190°C)

Table 1. Density values of test specimens

Treatments		X (g/cm^3)	sd	N
Unimpregnated	Unheated	0.776 ^{B}	0.0119	20
	150 °C	0.735 ^{D}	0.0185	20
	170 °C	0.703 ^{F}	0.0140	20
	190 °C	0.686 ^{H}	0.0085	20
Ia	Unheated	0.787 ^{A}	0.0114	20
	150 °C	0.741 ^{C}	0.0141	20
	170 °C	0.713 ^{E}	0.0211	20
	190 °C	0.694 ^{G}	0.0168	20
Ta	Unheated	0.791 ^{A}	0.0115	20
	150 °C	0.746 ^{C}	0.0139	20
	170 °C	0.715 ^{E}	0.0168	20
	190 °C	0.692 ^{FG}	0.0124	20

HG: Homogenous groups, letters in each column indicate groups that are statistically different according to LSD multiple range test at P < 0.05. sd: Standard deviation; N: Number of samples. X: Average density

Results of tests showed that increasing temperature significantly reduced air-dried density, which this situation can be explained by the degradation of chemical components into volatile products and the evaporation of extractive materials due to heat treatment [25]. Yildiz [26] conducted research on heat-treated spruce (*Picea orientalis*) and beech (*Fagus orientalis*) woods, mentioned that heat-treated samples at 200 °C for 10 h. density decreased 10.53% and 18.37%, respectively. Thermal degradation of wood material depends on wood species and process conditions such as treatment stage, treatment temperature and duration [27,28].

The results of the analysis of variance of the impregnation and heat treatment effects on temperature and light density of flame source combustion and without flame source combustion stages presented in Table 2.

According to the variance analysis, the effects of impregnation chemicals and heat treatment temperatures and the interaction of factors were found statically meaningful at 95 significance level on combustion

Table 2. Results of the analysis of variance

Combustion properties	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Sig. (P<0.05)
Temperature of FSC	Factor A	2	7742.000	3871.000	32.3707	0.0000
	Factor B	3	9364.750	3121.583	26.1038	0.0000
	AxB	6	1538.000	256.333	1.1436	0.0852*
	Error	24	2870.000	119.583		
	Total	35	21514.750			
Temperature of WFSC	Factor A	2	2440.500	1220.250	16.1623	0.0000
	Factor B	3	7506.750	2502.250	33.1423	0.0000
	AxB	6	1609.500	268.250	3.5530	0.0116
	Error	24	1812.000	75.500		
	Total	35	12766.750			
Light density in FSC	Factor A	2	4387.722	2193.861	27.1873	0.0000
	Factor B	3	6198.083	2066.028	25.6031	0.0000
	AxB	6	513.167	85.528	1.0599	0.4132*
	Error	24	1936.667	80.694		
	Total	35	13035.639			
Light density in WFSC	Factor A	2	4335.167	2167.583	14.1160	0.0000
	Factor B	3	6414.889	2138.296	13.9252	0.0000
	AxB	6	1716.611	286.102	1.8632	0.1290*
	Error	24	3685.333	153.556		
	Total	35	16152.000			

*Statistically not significant (P<0.05); Factor A: Impregnation chemical; Factor B: Treatment temperature properties except for temperature of FSC, light density in FSC, light density in WFSC.

Table 3. Average temperature and light density values of impregnation and heat treatment

Process type		Flame Source Combustion		Without Flame Source Combustion	
		Combustion temperature (°C)	Light Density (Lux)	Combustion temperature (°C)	Light Density (Lux)
Impregnation Solutions*	Unimpregnated	518 A	455 A	521 A	443 A
	Ia	486 B	428 C	501 C	422 B
	Ta	515 A	446 B	513 B	418 B
Heat treatment**	Unheated	484 C	423 C	489 C	406 C
	150 °C	499 B	440 B	515 B	427 B
	170 °C	521 A	454 A	529 A	439 A
	190 °C	523 A	456 A	517 B	441 A
LSD		*9.063 **10.47	*7.445 **8.597	*7.201 **8.315	*10.27 **11.86

The effect of impregnation materials on combustion temperatures and light density were found to be statistically insignificant (α <0.05). As seen from Table 3, a general reduction was showed in the temperature and light density values after combustion test in impregnation solutions, while a little increased the combustion temperature and light density values in heat treatment. In a similar research, Keskin [3] was impregnated LVL woods obtained from European oak (*Quercus petraea* Liebl.) and lombardy poplar (*Populus nigra* L.) with boron compounds, Ia, and Ta solutions. He reported that the treatment of wood samples with these chemicals caused significant improved to combustion properties compared to the unimpregnated samples. According to impregnation solutions the light intensity decreased due to the increase in smoke production in the stages of FSC and WFSC (Table 3).

On the other hand, the highest combustion temperature in the FSC and WFSC were determined at 190°C and at 170°C, respectively. The effect of heat treatment on combustion temperatures and light density were found to be statistically insignificant (α <0.05). In general, combustion temperature increased with increasing heat treatment temperature. This may be due to on the

decrease of equilibrium moisture content of heat-treated wood. It is well known that heat-treated wood has lower equilibrium moisture content compared to the unheated wood [29]. Also, light density increased with increasing heat treatment temerature. In other words, the smoke density of wood samples was reduced after the heat treatment. The highest smoke densities of FSC and WFSC stages were found on unheated wood.

Smoke production is an important factors for wood safety during the combustion in wood production industry [30]. Heat-treated test specimens have significantly decreased values of smoke density comparing to untreated specimens. This may be due to the removal of some volatile organic materials in the wood during the heat treatment. Müllerová [11] reported that wood material contains organic and inorganic matters and total volatile

Table 4. Duncan’s test results of interaction between impregnation material and heat treatment

Impregnation Process	Heat Treatment	Flame Source Combustion		Without Flame Source Combustion	
		Combustion temperature (°C)	Light Density (Lux)	Combustion temperature (°C)	Light Density (Lux)
Unimpregnated	Unheated	486 FGH	436 EF	506 E	432 BCD
	150 °C	507 CDE	452 BCD	517 CDE	443 AB
	170 °C	539 AB	465 AB	528 ABC	457 A
	190 °C	543 A	467 A	535 AB	441 ABC
Ia	Unheated	469 H	401 G	475 E	398 EF
	150 °C	479 GH	425 F	507 DE	417 DE
	170 °C	491 EFG	441 DE	520 BCD	428 BCD
	190 °C	506 CDE	447 CDE	503 E	444 AB
Ta	Unheated	498 DEF	432 EF	487 F	389 F
	150 °C	511 CD	443 CDE	521 BCD	421 CD
	170 °C	533 AB	457 ABC	539 A	433 BCD
	190 °C	521 BC	453ABCD	508 DE	432 BCD
LSD		18.13	14.89	15.06	34.43

organic compounds decreased due to heat treatment. According to Manninen et al. [18] heat treatment releases volatile components from the wood material, which are closely related to the combustion properties of wood. For this reason, heat-treated wood contains lower volatile flammable components comparing to the un-heated wood[31].

The results of Table 4 demonstrated that the impregnation materials and heat treatment significantly affected combustion properties of the wood. In generally, temperatures of FSC lower than temperatures of WFSC. However light density of FSC higher compared to those of the WFSC. In FSC, Duncan's test results for the interaction of impregnation material and heat treatment was recorded as highest temperature with unimpregnated and heat-treated specimens at 190 °C (543°C) and lowest impregnated with Ia and unheated samples (469°C). In WFSC, higest temperature was measured as 539 °C in impregnated with Ta and heat-treated samples at 170 °C, while the lowest value as 475 °C in impregnated with Ia and unheated samples.

According to Table 4, in FSC, the highest light density was recorded as 467 Lux in unimpregnated and heat-treated specimens at 170 °C, the lowest as 401, in impregnated with Ia and unheated samples. In WFSC, the highest light density was recorded as 457 Lux in unimpregnated and heat-treated specimens at 190 °C, the lowest as 389 in impregnated with Ta and unheated samples.

The findings from Table 4 showed that in generally, impregnation material showed a decreasing effect on combustion temperature and light density. On the other hand, experimental results show that as the heat treatment temperature increases combustion temperature was increased, however meanwhile, smoke production was decreased in generally. In literature there are several studies that deal with the combustion properities of heat-treated wood. Xing and Li [32] studied combustion properties of heat-treated Larix wood. Test results showed that heat treatment showed positive effects on the fire safety of Larix wood, weakening the intensity of its combustion properties and also reducing the ignition time. Osvaldová and Gaff [33] determined retardation effect on heat-treated spruce wood. They reported that, heat-treated fire retardant treated samples have lower weight losses than non-treated samples. Yasar et al. (2017) [34] also reported that impregnation chemicals effects the combustion characteristics of wood material. In a similar study, Čekovsá et al. [35] studied that higher heat treatment temperatures caused higher combustion rate on spruce specimens and burning stopped suddenly with the removal of the flame source during combustion. In another study, Budakçı et al. 2016 [36] studied that Scots pine (*Pinus sylvestris* L.) and Oriental beech (*Fagus orientalis* L.) samples coated with waterbased varnish which was modified with 5% boric acid at varied amount (10%, 20%, and 30%) and then determined combustion properties of samples. According to the test results, when increase the boric acid ratio in varnish the combustion resistance increased.

4. CONCLUSIONS

The combustion properties of impregnated and heat-treated hornbeam wood was determined in the study. The impregnation chemicals and heat treatment changed combustion temperatures and light densities of hornbeam wood. Combustion temperature of impregnated samples in the FSC stage was lower than unimpregnated samples and combustion temperature increased significantly as the heat treatment increased. In terms of light density in FSC stage, while impregnation materials caused higher smoke production, heat treatment decreased smoke production. In the WFSC stage, combustion tempereatures of impregnated samples lower than those of the unimpregnated. In addition temperatures of heat-treated samples higher than unheated samples. In terms of light intensity, decrease values in the impregnated samples provided evidence increase of the smoke production were result of the impregnation process. The light density increased in heat-treated hornbeam samples depending on decreased smoke production. The combustion properties of impregnated and heat-treated wood should be further investigated.

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