academicJournals

Vol. 8(19), pp. 1022-1028, 23 May, 2013
DOI: 10.5897/IJPS12.690
ISSN 1992-1950 © 2013 Academic Journals
http://www.academicjournals.org/IJPS

International Journal of Physical Sciences

Full Length Research Paper

Combustion properties of Rowan wood impregnated with various chemical materials

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Accepted 24 April, 2013

The common use of Rowan wood (*Sorbus aucuparia* Lipsky) in the forest products industry of Turkey, was evaluated for some of the combustion properties after impregnation with various chemical materials. For this purpose, the wood test samples prepared from Rowan wood materials according to TS 345 were treated with Tanalith-E, Vacsol-Azure, Imersol-Aqua and Boron compounds (Borax and Boric asid) by the vacuum impregnation process in accordance with ASTM D-1413 standards and directives of the manufacturer. After impregnation, each sample was tested for observation of retention amount and combustion properties (ASTM E 160-50). It has been proven that combustion properties of the impregnated Rowan wood materials were affected by impregnated materials. As a result, combustion temperature was measured as highest in Imersol Aqua (458.686°C) and the lowest in Borax (439.023°C). The impact of impregnation material decreases after the ignition and the main impact was in flame sourced combustion. In addition, boric acid reduces the material loss in combustion, ensuring that the material is more resistant to sudden collapse and destruction. As a result, it appears that impregnation of wood material with appropriate boron treatment will further increase combustion temperatures and provide additional fire resistance and a degree of security.

Key words: Rowan wood, combustion properties, Tanalith-E, Vacsol-Azure, Imersol-Aqua, Boron compounds.

INTRODUCTION

If the wood materials are used without processing by preservative chemicals (with regard to the area of usage), fungal stains, insect infectation, humidity, fire etc. damage the wood. As a result of these damages, the woods require to be repaired, maintained or replaced before its economic life ends (Richardson, 1987). For this reason, in most places the wood materials should be impregnated with some proper chemicals. For this purpose, ammonium sulfate, ammonium chloride, borax, boric acid, phosphoric acid, etc., are used mostly. In the case of wood not impregnated but only painted and varnished, the prevention on the surfaces is limited to a maximum of two years (Evans et al., 1992).

In a research which was conducted by Örs et al. (1999a), wood samples prepared from Scotch pine (*Pinus sylvestris* L.) and chestnut (*Castanea sativa* Mill.) were impregnated with tanalith–CBC, water repellent (WR) solutions + synthetic varnish and WR + polyurethane varnish. Afterwards, synthetic and polyurethane varnishes were applied to the surfaces. Impregnation with T-CBC was not retarding combustion in both types of wood, but the weight loss occurs as 20% in chestnut and

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13% in yellow pine. Varnishing after the impregnation did not affect combustion properties. Furthermore, the alder wood was impregnated with boron compounds to keep from the biotic and abiotic and observed that boron compounds decreases the combustion in great extent (Uysal, 1998). On the ther hand, Douglas wood was impregnated with boron compounds and PEF-400 to observe the changes in the combustion properties (Yalınkılıç et al., 1997) and polyethylene glycol groups was affected negatively but boron compounds have positive impact on combustion.

Wood and wood-based materials consist of organic compounds and are composed mainly of carbon and hydrogen; for this reason, they are combustible. For ignition, oxygen, flame source and flammable material are necessary. The combustibility of the wood is favorable when it is used as a fuel, but unfavorable as a building material. It is impossible to make wood incombustible but it is possible to make it fire resistant (Baysal, 2011). Wood has excellent natural fire resistance as a result of its remarkably low thermal conductivity and the fact that wood char is formed when wood is burned. In order to reduce flammability and provide safety, wood is treated with fire-retardant chemicals. In other words, the combustibility of wood may be reduced with flameretardant or fire-retardant materials (Özçifçi, 2001a; Örs et al., 1999b). The most commonly used fire retardant chemicals in the wood industry are inorganic salts including ammonium and diammonium phosphate, ammonium chloride, ammoniumsulfate, borax, boric acid, phosphoric acid, and zinc chloride. Fire-retardant chemicals drastically reduce the rate at which flames travel across the wood surface, thereby reducing the capacity of the wood to contribute to a fire (Atar and Keskin, 2007; Atar et al., 2011).

Combustion properties of wood are important because of safety issues since it is one of the more commonly available flammable materials. Its combustion process is well studied particularly for modified woods which have been treated to resist burning (Baysal et al., 2003; Peker et al., 2004; Terzi, 2008; Seferoğlu, 2008).

In addition, wood-based materials such as plywood, OSB and MDF panels (Aslan and Özkaya, 2004), and laminated panels (Özen et al., 2001a; Uysal and Özçifçi, 2000; Özçifçi, 2001b; Okcu, 2006; Özkaya, 2002; Uysal and Kurt, 2006) have been investigated.

This study was performed to determine the impacts of vacuum impregnation process with various chemical materials (Tanalith-E, Vacsol-Azure, Imersol-Aqua, Borax and Boric asid) on the combustion properties of Rowan wood.

MATERIALS AND METHODS

Wood materials

Test samples were obtained from Kastamonu Forestry Regional Directory, Küre Directory, Kösreli Department number 200. Test samples were cut from the trees in accordance with TS 4176 (1984) standard. Recently use of Rowan wood is getting more popular in Turkey and surrounding countries due to its high demand. Test samples are prepared in accordance with TS 2470 (1976) and TS 53 (1981). Accordingly, non-deficient, knotless, normally growth (without zone line, without reaction wood and without decay and insect mushroom damage) wood materials was selected. Test samples cut to 70×70×800 mm were air-dried at 20±2°C temperature and 65±3% relative humidity conditions reaching up to 12% humidity level.

Impregnation material

Tanalith-E

Tanalith-E is an impregnation material used against the attacks of agent, yeast, insect and termite. It is a new generation of impregnation material consisting of copper and organic biocide (triazole) and not harmful to plant, animal and human health. Tanalith-E, light green in color, odor, pH 7, 104 g/cmP^3 density, smooth and completely water-soluble, water-based, non-corrosive to metal parts are available in the form of ready solution. Tanalith-E was applied to woods used in fences, railings, garden furniture, barns, silos, farm buildings, the wood used in children's play areas by vacuum - pressure method (Hickson's Timber Impregnation Co. (GB), 2000).

Vacsol Azure

Vacsol Azure a product of a new technology developed by using active ingredients, used in the process, ground wood materials on the level of fungi, insects (Propiconazole and tebuconazole), and termites (permethrin) to prevent decay by protecting against transparent impregnating agent. This solvent-based material is water-insoluble, pale yellow in color, flammable, density 0.806 g/cm^3 at 20±2°C, contains 64% of Volatile Organic Compounds (VOC) (Hickson's Timber Impregnation Co. (GB), 2000).

Imersol-Aqua

Imersol-AQUA, used as an impregnation material in this study was supplied from Hemel (Hemel-Hickson Timber Products Ldt.), Istanbul. Imersol-AQUA is non-flammable, odorless, fluent, water-based, completely, soluble in water, non-corrosive material with a pH value of 7 and a density of 1.03 g/cm^3. It is available as a ready-made solution. It contains 0.5 % w/w tebuconazole, 0.5 % w/w propiconazole, 1% w/w 3-Iodo-2-propynl-butyl carbonate and 0.5% w/w cypermethrin. Before the application of Imersol-AQUA on the wood material, all kinds of drilling, cutting, turning and milling operations should be completed and the relative humidity should be in equilibrium with the test environment. In the impregnation process, dipping duration should be at least 6 min and the impregnation pool must contain at least 15 L of impregnation material for 1 m^3 of wood. The impregnated wood should be left to dry for at least 24 h (Hickson's Timber Impregnation Co. (GB), 2000).

Preparation of the test samples

Using one type of wood, five different types of impregnation materials (Tanalith-E, Imersol Aqua, Vacsol Azure, Boric acid and Borax), eight types of combustion (flame sourced combustion temperature, without flame source combustion temperature, glowing stage combustion temperature, flame sourced combustion

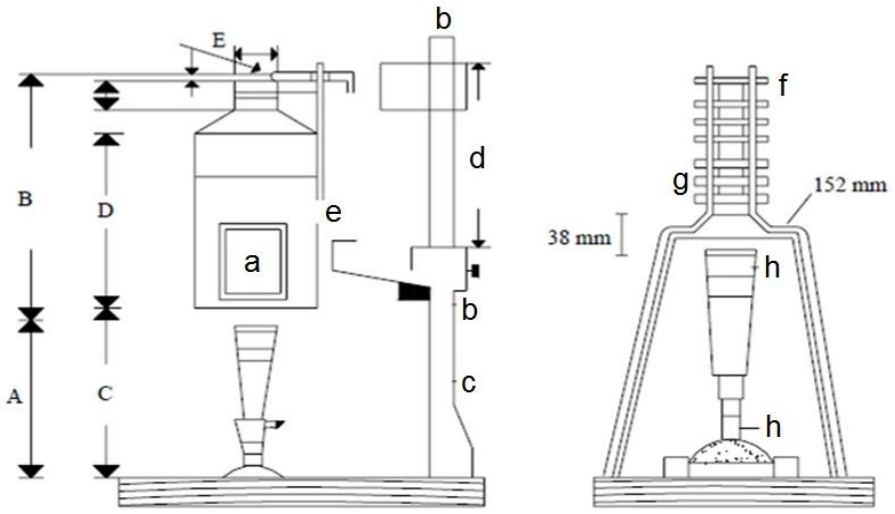

Figure 1. Combustion test apparatus. a: Mica glass b. End of slide, c: Flame burner guide, d: Slide, e: Potansiyometer or Milivoltmeter inlet, f: Test specimens, g: Wire cage, A: 270 mm., B: 430 mm., C: 295 mm., D: 305 mm., E: 38 mm.

light intensity, without flame sourced combustion light intensity, glowing stage combustion light intensity, combustion losses, combustion durations) and one control sample, a total of 450 (13×13×76 mm) samples were prepared with ten samples for each parameter.

Combustion tests

Combustion tests were done in combustion test devices according to ASTM E 160-50 (1975) standards. Accordingly, before the combustion test, impregnated samples were conditioned at 27°C and 30% relative humidity in a conditioning room until reaching 7% relative humidity. Every sample group was weighed before the test and stored on a wire stand. Samples on every stand were placed vertically on the stand with respect to the samples below and above. Distance between samples and the fire-flame outlet was fixed at 25±1.3 cm when the device was empty and gas pressure was fixed at 0.5 kg/cm^2 in the manometer. When ignited, the test temperature was set at 315±8°C in the funnel, using a calibrated thermocouple. The flame source was centered below the sample pile and the flame source combustion was continued for three minutes. After extinguishing the flame source, subsequent evaluation of flame spread (charring) without open-flame source combustion was carried out. Temperatures during combustion (°C) were determined with a thermometer (Figure 1). Without flame source cumbustion duration is the duration of combustion after the flame source turned-off up to flame source combustion. The glowing stage combustion duration is the duration from flame sourced combustion to dispersion of test samples.

Data analysis

SPSS 15.0 for Windows program is used in the statistical analysis of the combustion properties of the wood material tested. Multiple variance analysis was used to determine the difference between the combustion properties of the impregnated samples. In the case of significant difference between the groups (α = 0.05) confidence level was compared with Duncan's test. Factor that led to the success of the experiment was each other's rankings; least significant difference (LSD) was determined by leave of critical groups according to the value of homogeneity.

RESULTS

Combustion properties

Combustion temperatures

Mean values of combustion temperatures, light density, weight loss and combustion duration for different combustion types are given in Table 1.

The highest combustion temperature for burning types was found in without flame burning (570.160°C) and the lowest in glowing stage burning (259.511°C). The highest light density was measured in flame combustion (342.179 lux) and the lowest glowing stage (285.683 lux). Weight loss for different combustion types were found as equal (84.890%). Combustion duration was the highest in glowing stage combustion (9.055 min) and the lowest in without flame combustion (2.558 min).

Mean values of combustion temperatures, light density, weight loss and combustion duration for different impregnation materials are given in Table 2.

The highest combustion temperature for different impregnation materials was measured in Imersol Aqua (458.686°C) and the lowest in Borax (439.023°C). The highest light density was measured in Borax (343.337 lux) and the lowest in Vacsol Azure (294.102 lux) impregnation. The weigth loss was the highest in Imersol Aqua (91.667%) and the lowest in boric acid (78.333) impregnation. Combustion duration was the highest in Borax (6.888 min) and the lowest in Vacsol Azure (4.112 min).

Table 1. Mean values of combustion temperatures, light density, weight loss and combustion duration for different combustion types.

Combustion type	Temperature (°C)*	Ligtht density (lux)**	Weight loss (%)***	Combustion duration (min)****
AKY	520.216 ^{A}	342.179 ^{A}	84.890 ^{A}	3.500 ^{B}
KKY	570.160 ^{A}	312.318 ^{A}	84.890 ^{A}	2.558 ^{C}
KHY	259.511 ^{B}	285.683 ^{A}	84.890 ^{A}	9.055 ^{A}

*Different letters in the columns refer to significant changes in the combustion temperatures at 0.05 confidence level ($LSD_{0.5}$= 60.920); **different letters in the columns refer to significant changes in the light density at 0.05 confidence level ($LSD_{0.5}$= 54.120); ***different letters in the columns refer to significant changes in the weight loss at 0.05 confidence level ($LSD_{0.5}$= 1.401), ****different letters in the columns refer to significant changes in the combustion duration at 0.05 confidence level ($LSD_{0.5}$= 55.650).

Table 2. Mean values of combustion temperatures, light density, weight loss and combustion duration for different impregnation materials.

Impregnation material	Temperature (°C)*	Ligtht density (lux)**	Weight loss (%)***	Combustion duration (min)****
Control (Co)	436.840 ^{A}	293.282 ^{A}	84.667 ^{B}	3.110 ^{D}
Vacsol Azure (Va)	454.204 ^{A}	294.102 ^{A}	84.000 ^{B}	4.112 ^{CD}
Tanalith E (Te)	458.442 ^{A}	329.055 ^{A}	86.000 ^{B}	5.0 ^{BC}
Imersol Aqua (Ia)	458.686 ^{A}	320.690 ^{A}	91.667 ^{A}	5.777 ^{AB}
Borik Asit (Ba)	452.578 ^{A}	299.894 ^{A}	78.333 ^{C}	5.337 ^{BC}
Borax (Bx)	439.023 ^{A}	343.337 ^{A}	84.667 ^{B}	6.888 ^{A}

*Different letters in the columns refer to significant changes in the combustion temperatures at 0.05 confidence level ($LSD_{0.5}$= 86.160); **different letters in the columns refer to significant changes in the light density at 0.05 confidence level ($LSD_{0.5}$= 76.530); ***different letters in the columns refer to significant changes in the weight loss at 0.05 confidence level ($LSD_{0.5}$= 1.981), ****different letters in the columns refer to significant changes in the combustion duration at 0.05 confidence level ($LSD_{0.5}$= 78.700).

Multiple variance analysis (MANOVA) results of combustion temperature, light density, weight loss and combustion duration for different impregnation materials are given in Table 3.

According to this result, the impact of impregnation material type on combustion temperature, weight loss and combustion duration were found statistically meaningful ($\alpha < 0.05$). Accordingly, the impact of impregnation material type on light density was found as statistically unmeaningful ($\alpha < 0.05$).

Duncan's test results of interaction between impregnation material and combustion type is given in Table 4.

According to Duncan's test, the interaction between the impregnation material and combustion type was the highest in Ba+KKY (618.600°C) and the lowest in Ba+KHY (212.387°C). Duncan's test results of impregnation material and combustion type interaction was the highest for Ia+AKY, Ia+KKY, Ia+KHY (91.670%) and the lowest for Ba+AKY, Ba+KKY, Ba+KHY (78.330%). Duncan's test results for the interaction of impregnation material and combustion type was found as the highest in Bx+KHY (11.833 min) and the lowest in Va+KKY (1.505 min).

DISCUSSION

The amount of retention according to the type of impregnation material was found statistically meaningful. This may be due to difference in concentrations of impregnation solution. The highest amount of retention was obtained in Vacsol Azure, followed by Imersol Aqua, Tanalith-E, borax and boric acid. According to the type of impregnation material, the highest retention amounts were measured in Vacsol Azure samples (151.044 kg/m^3) followed by Imersol-Aqua (127.045 kg/m^3), Tanalith-E (104.083 kg/m^3), Borax (86.393 kg/m^3), boric acid (64.887 kg/m^3). The highest amount of retention in Vacsol Azure impregnation may be due to the difference in concentration and the impregnation capacity.

The impact of impregnation material on combustion temperature was found statistically meaningful ($\alpha<0.05$). Combustion temperature was measured as 454.204°C with Vacsol Azure, 458.442°C with Tanalith-E, 458.686°C with Imersol Aqua, 452.578°C with Boric acid, 439.023 °C with Borax and 436.840°C with control samples. Boron compounds decreased the combustion temperature as mentioned in the literature. The combustion temperatures was measured as 520.216°C with flame sourced combustion, 570.160°C without flame sourced combustion and 259.511°C with glowing stage combustion. The effect of impregnation material decreases after ignition has occurred, thus the main effect of impregnation material is during the flame sourced combustion.

The light intensity according to the type of impregnation materials was measured as the highest with

Table 3. Multiple variance analysis results of combustion temperature, light density, weight loss and combustion duration for different impregnation materials.

Factor	Degree of fredom	Sum of squares				Mean of squares				F value				P significance value (α < 0.05)			
		Combustion temperature	Light density	Weight loss	Combustion duration	Combustion temperature	Light density	Weight loss	Combustion duration	Combustion temperature	Light density	Weight loss	Combustion duration	Combustion temperature	Light density	Weight loss	Combustion duration
Impregnation material (A)	5	4182.272	19385.521	819.333	279693.722	836.454	3877.104	163.867	55938.744	0.100	0.591	37.336	8.073	0.000	0.126	0.000	0.000
Temperatures (B)	2	1001786.907	28757.947	0.000	1597640.333	500893.453	14378.974	0.000	798820.167	60.327	2.194	0.000	115.296				
Interaction (AB)	10	21178.695	44421.733	0.000	81567.444	2117.870	4442.173	0.000	8156.744	0.255	0.678	0.000	1.177				
Error	36	298905.916	235855.975	158.000	249423.333	8302.942	6551.555	4.389	6928.426								
Total	53	1326053.790	328421.177	977.333	2208324.833												

Table 4. Duncan's test results of interaction between impregnation material and combustion type.

Impregnation material + Combustion type	Temperature (°C)*	Weight loss (%)**	Combustion duration (min)***
Co+AKY	514.275 ^{A}	86.670 ^{B}	2.666 ^{FGH}
Co+KKY	548.244 ^{B}	86.670 ^{B}	0.500 ^{H}
Co+KHY	248.000 ^{A}	86.670 ^{B}	6.166 ^{DE}
Va+AKY	531.025 ^{A}	84.000 ^{B}	3.166 ^{FG}
Va+KKY	572.853 ^{B}	84.000 ^{B}	1.505 ^{GH}
Va+KHY	258.733 ^{A}	84.000 ^{B}	7.666 ^{CD}
Te+AKY	509.388 ^{A}	86.000 ^{B}	3.666 ^{EFG}
Te+KKY	563.472 ^{A}	86.000 ^{B}	2.333 ^{FGH}
Te+KHY	302.467 ^{B}	86.000 ^{B}	9 ^{BC}
Ia+AKY	533.111 ^{A}	91.670 ^{A}	2.833 ^{FGH}
Ia+KKY	570.955 ^{A}	91.670 A	4.333 ^{EF}
Ia+KHY	271.991 ^{B}	91.670 ^{A}	10.166 ^{AB}
Ba+AKY	526.747 ^{A}	78.330 ^{B}	4 ^{EFG}
Ba+KKY	618.600 ^{A}	78.330 ^{B}	2.511 ^{FGH}
Ba+KHY	212.387 ^{B}	78.330 ^{B}	9.500 ^{ABC}
Bx+AKY	506.750 ^{A}	84.670 ^{C}	4.666 ^{EF}
Bx+KKY	546.833 ^{A}	84.670 ^{C}	4.166 ^{EF}
Bx+KHY	263.487 ^{B}	84.670 ^{C}	11.833 ^{A}

*Different letters in the columns refer to significant changes in the combustion temperatures at 0.05 confidence level ($LSD_{0.5}$= 149.200); **different letters in the columns refer to significant changes in the weight loss at 0.05 confidence level ($LSD_{0.5}$= 3.431), ***different letters in the columns refer to significant changes in the combustion duration at 0.05 confidence level ($LSD_{0.5}$= 136.300).

Borax (343.337 lux) and the lowest with Vacsol Azure at (294.102 lux) respectively. The effect of the type of impregnation material on light intensity was found to be statistically insignificant (α <0.05). The light intensity according to the type of impregnation materials was found as 294.102 lux (Vacsol Azure), 329.055 (Tanalith-E), 320.690 lux (Imersol Aqua), 299.894 Lux (Boric acid), 343.337 (Borax) and 293.282 (control samples), respectively. Accordingly, the highest light intensity was measured in Borax as 343.337 lux and the lowest in Vacsol Azure as 294.102 lux. Boron compounds show a positive effect on the density of the smoke as a source of poisoning but not such a risk with other impregnation materials.

Light density according to type of combustion was measured as 342.179 lux with flame sourced combustion, 312.318 lux without flame sourced combustion and 285.683 lux in glowing stage combustion. Smoke does not occur in glowing stage combustion but at the same level with and without flame sourced combustions. Duncan's test results for the interaction of impregnation material and combustion type was measured as the highest with Bx+AKY as 350.639 lux and the lowest with Ba+KHY as 226.740 lux.

The impact of impregnation material type on weight loss was found statistically meaningful (α < 0.05). Weght loss was measured as 84.000% with Vacsol Azure, 86.000% with Tanalith-E, 91.667% with Imersol Aqua, 78.333% with Boric acid, 84.667% with Borax 84.667% with control samples. Thus it was highest with Imersol Aqua (91.667%) and lowest with Boric acid (78.333%). Weight loss for different combustion types was measured as the same (84.890%). Boric acid is more resistant to material loss, decreasing the risk of a sudden collapse and destruction in fire.

Duncan's's test results for the interaction of impregnation material and combustion type was measured as highest with Ia+AKY, Ia+KKY, Ia+KHY (91.670%) and as lowest with Ba+AKY, Ba+KKY, Ba+KHY (78.330%).

The impact of impregnation material on combustion type was found statistically meaningful (α<0.05). The combustion duration for different impregnation materials was measured as 4.112 min with Vacsol Azure, 5 min with Tanalith-E, 5.777 min with Imersol Aqua, 5.337 min with Boric acid, 6.888 min with Borax and 3.110 min with control samples. So, it was highest with Borax (6.888 min) and lowest with Vacsol Azure (4.112 min). Combustion duration according to type of combustion was measured as 3.500 min with flame sourced combustion, 2.558 min without flame sourced combustion and 9.055 min in glowing stage combustion. Thus, combustion duration was highest with glowing stage combustion (9.055 min) and lowest without flame sourced combustion (2.558 min). Duncan's test results for the interaction of impregnation material and combustion type were measured and the highest was 11.833 min with Bx+KHY and the lowest 1.505 min with Va+KKY.

Consequently, the boron compounds showed a positive effect on combustion properties of Rowan wood.

In this study, the combustion properties of Rowan wood were determined by impregnating it with various impregnation materials (Tanalith-E, Vacsol-Azure, Imersol-Aqua and Boron compounds (Borax and Boric asid)). These properties can be compared with the results of other studies in literature which are related to the effects of various impregnation materials on combustion properties of different tree species.

Yalınkılıç et al. (1998) investigated the combustion properties of Douglas wood impregnated with different agents to keep it from biotic and abiotic effects. They observed that boron compounds have impacts to decrease the combustion.

Örs et al. (1999c) researched the combustion increase impact of poly ethilenglicol (PEG-400) and WR. So yellow pine wood was treated with paraffin, styrene, methil metacrilate and izosiyanat after being impregnated with boric acid, borax and sodium per borate solutions with water or PEG-400. It was observed that boron compounds increases the combustion resistance and decreases the combustion impact of water repellents.

Özen et al. (2001b) impregnated yellow pine with sodium per borate, sodium tetra borate, Imersol-Aqua and Tanalith–CBC by dipping method and studied combustion properties of D-VTKA glued 3-ply laminates in accordance with ASTM E69 standard (ASTM, 1976). They observed sodium tetra borate and sodium per borate as the agents that negatively affect the combustion process.

Örs et al. (2002) investigated the combustion properties of heaven wood impregnated with Tanalith-CBC, Borax, Boric acit, Boric acid + Borax, Vacsol-WR, Imersol-WR 2000, Polietilenglikol-400 and Stiren. As a result of the tests, the boron compounds with vacuum process increased the fire reterdant of the heavenwood species growing in Turkey. It was observed that one of the vinil monomers Styrene and Vacsol-WR has shown a fire retardant effect.

Baysal (2003) carried out the combustion properties of yellow pine impregnated with boric acid, borax and tanning materials. Natural extractives showed unfavourable effects on fire parametres. Also, they showed the same or more badly burning properties compare to control specimen. However, boric acid and borax applied as secondary treatment agents over natural extractives possivitely affected some fire properties of Scots pine in significant level (P≤ 0.01).

ACKNOWLEDGMENTS

This study is a part of M.Sc.Thesis prepared by Neslihan SÜZER ERTÜRK, Institute of Science and Technology, Gazi University, Ankara, Turkey.

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