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# Improving the Fire Resistance of Heat Treated Wood by Using Environment-Friendly Substance

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## Abstract

The greatest risk of wood structures with many advantages is there ignition and burning. Negative property of wood can be reduced by using environmentally friendly substance. In this study, pine (*Pinus sylvestris* L.) wood samples were heat-treated at 210 ° C for 120 minutes after impregnation with boric acid in concentrations of 2.5% and 5%. Fire performance of the combination of boric acid (BA) and heat treatment was calculated from maximum temperature and weight loss. According to Mini Fire Tube (MFT) test results, 99,99% weight loss was observed in the control samples, while 38,36% and 52,24% weight loss were observed in 5% BA and 5% BA+Heat treatment respectively. 2.5% BA+Heat treatment and 5% BA+Heat treatment samples reached maximum weight loss in 160 seconds. While the maximum temperature increased to 444,73 ºC in 5% BA impregnated samples, it remained at 227.9 ºC in 2.5% BA + heated samples.

**Keywords:** Heat treatment, boron, fire resistance

# Çevre Dostu Madde Kullanılarak Isıl İşlemli Örneklerin Yanma Dirençlerinin İyileştirilmesi

## Özet

Ahşap malzemelerin avantajlarının yanında en büyük dezavantajları alevlenmeleri ve yanmalarıdır. Odunun bu negatif özelliği çevre dostu maddeler kullanılarak azaltılabilir. Bu çalışmada, çam (*Pinus sylvestris* L.) odun örnekleri,% 2.5 ve % 5'lik konsantrasyonlarda borik asit ile emprenye edildikten sonra 120 dakika süreyle, 210 ° C'de ısıl işleme tabi tutulmuşlardır. Bor ve ısıl işlem kombinasyonunun odunun yanma performansı üzerine etkisi maksimum sıcaklık ve ağırlık kaybı üzerinden hesaplanmıştır. Mini Fire Tube (MFT) test sonuçlarına göre kontrol örneklerinde% 99,99 ağırlık kaybı gözlenirken, % 5 BA ve % 5 BA + Isıl işlemli örneklerde sırasıyla % 38,36 ve % 52,24 ağırlık kaybı gözlenmiştir. % 2,5 BA + Isıl işlem ve % 5 BA + Isıl işlemli örnekler 160 saniyede maksimum ağırlık kaybına ulaşmıştır. % 5 BA emprenyeli örneklerde maksimum sıcaklık 444,73 ºC'ye yükselirken,% 2.5 BA + Isıl işlemdeki maksimum sıcaklık 227,9 ºC'de kalmıştır.

**Anahtar Kelimeler:** Isıl işlem, bor, yangın direnci

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# 1. Introduction

Wood is one of the most abundant materials in nature and has superior properties (low density, low heat conductivity, high mechanical strength, easy processability and a good aesthetic appearance) compared to other building materials. . However it may be subject to some significant surface changes as a result of the external environment such as UV rays, moisture (rain, snow, humidity, flooding), mechanical effects (wind, dirt), temperature and atmospheric factors ($O_2$, $SO_2$, pollutant gases). Many techniques are used to increase the life of wood at the site of its utilization, the most important ones being wood impregnation and wood modification. Thanks to these methods, the negative properties of wood can be improved (Can, 2011).

One of the methods used to modify the properties of wood is heat treatment. No chemical used in heat treatment applicationand therefore it is considered as an environmentally friendly method (Kamdem et al., 2000; Yildiz, 2002; Gündüz et al., 2008). With heat treatment, the specific weight of the wood is reduced, the heat insulation property is increased, color homogeneity is achieved, the biological properties are improved and the wood becomes easily processable. In addition to these positive characteristics, the flammability properties of some wood samples have been enhanced after heat treatment. For wood material, thermal decomposition begins after reaching the point of 100 °C. At temperatures above 200 °C, structural damage, complete conversion of the wood material components and the release of gas phase degradation products will occur. Pyrolysis and the combustion of wood material are initiated when temperatures reach more than 270 °C (Fengel and Wegener 1989).

Various studies have been carried out to reduce the flammability properties of heat-treated samples. Environmentally friendly boron compounds have high fire resistance and have been used for this purpose. Boron suppresses combustion of the burning material by cutting off the contact with oxygen. Zinc borate is used for plastic materials, while soluble borates such as boric acid, borax pentahydrate and borax decahydrate are used for cellulosic materials (URL-1). When exposed to heat, boron compounds create a glassy structure in the wood which reduces the spread and rate of flammable gases and prevents the development of thermal degradation products (LeVan and Tran, 1990). The cell walls are then blocked and the degradation compounds trapped within this structure, thereby retarding combustion. Furthermore, when exposed to heat, the boron compounds are responsible for a chemical bond between the cellulose fibers. This results in a reduction of mass at the initial temperature of pyrolysis of the wood and cellulose (Yamaguchi, 2003). Boric acid reduces the combustion, but does not prevent the spread of the flame.

In this study, the resistance of the wood material against combustion was examined with heat treatment application. In this context, the combustion performance of heat-treated and boron compound-impregnated Scots pine wood samples was tried to be determined using the Mini Fire Tube test method.

# 2. Material and Methods

## Materials

Scots Pine (*Pinus sylvestris* L.) wood samples obtained from an industrial plant in Turkey. Test and control samples were prepared from sapwood blocks with dimensions of 5x10x100 mm (height x width x longitudinal). These well-selected specimens were no deficient, proper, knot-free, normally grown wood material (without reaction wood and without decay, insect and fungal attack) according to the principles of TS 2470 (1976).

## Methods

5 control samples, 5 test samples impregnated with BA, totally 10 samples were prepared. In addition, 15 heat treatment samples have been prepared. Before the experiment, the test samples were dried until they were stable at 20±2◦C, 60±5% relative humidity and 12% moisture gradient in climate room.

## Impregnation of Wood

Wood samples treated with 2.5% and 5% aqueous solution of boric acid (BA) at 650 mm-Hg vacuum for 30 min. and a pressure of 5 bar for 60 min. at room temperature. After the treatment, specimens were re-weighed to determine the boric acid (BA) retention. All treated specimens were then reconditioned at 20±2 OC and %65±5 RH for 2 weeks (ASTM D 1413-76).

The retention content for each treatment was calculated following formula.

$R(kg/m^3)=((G\times C)/V)\times 10$ (1)

Where;

G is the difference between sample weight after impregnation and sample weight before impregnation (kg), C is the concentration (%), and V is the sample volume ($m^3$).

## Heat Treatment of Wood

Heat treatment was done in an oven. Water vapor and other gas are not in the environment. Wood samples were subjected to heat treatment at 210 °C for 2 hours, including untreated and boron pretreated samples.

## MFT – Mini Fire Tube Method

The MFT (Mini Fire Tube) method is an adopted and a modified ASTM E69 (2002) method (Figure 1). Profile tube made of aluminium (2 x 2 cm) with stand is placed on the laboratory weight. The source of heat is a gas burner with adjustable flame height (preferred height is 1 cm), mounted on a tripod. Measurement of exhausted gases temperature at the outlet of the pipe was made by using a type K thermocouple display for the temperature range 50-1200 $^0$C.

The samples left loosely arranged after the protection procedure for a period of 7 days in order to dry. Before the test, the samples should be pre-drilled with the holes for suspension in the tube.

The performance test of the effect of protective system carried out according to the methods similar to the ASTM E69 method. After the placing the sample in the tube, on the hook and placing it on a laboratory weight, the weight tarred. During sample combustion the display show the result of proper mass loss. A burner was placed with the height of the flame ca. 1 cm under a suspended sample. The duration of the flame on the sample was regulated and should amount to 6 minutes. The mass loss and the value of action gas temperature at the outlet of pipe shall be recorded at intervals of 2 seconds.

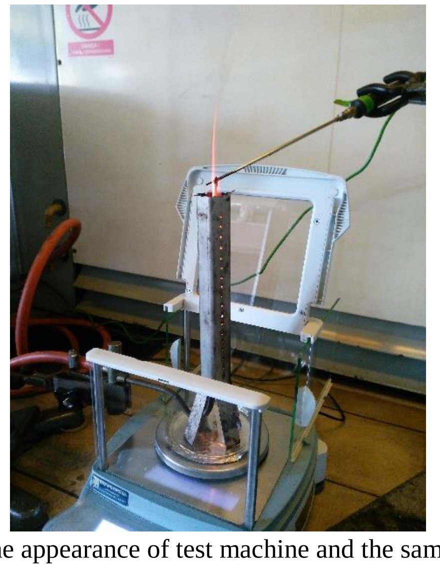

Figure 1. The appearance of test machine and the sample burning

Mass loss

The main evaluation criterion was the mass loss of the test samples which was calculated according to Eq. 2,

$\Delta m=((m1-m2)/m1)x100$ (2)

Where;
Δm: mass loss (%), m1: sample's weight before the test (g), m2: sample's weight after the test (g),

## 3. Results and Discussion

The weight loss values of the samples after the combustion test are shown in Figure 2 and the maximum temperature values reached in the test case are given in Figure 3.

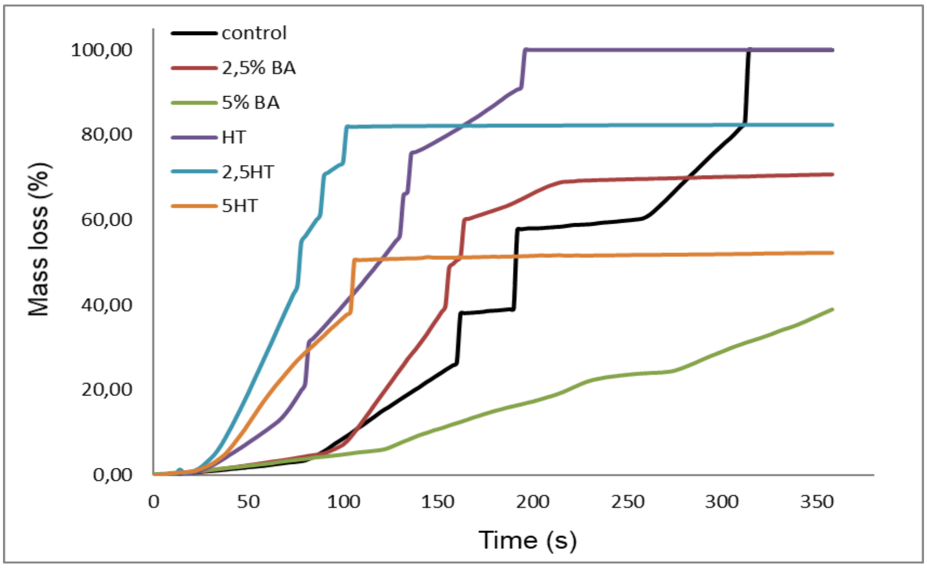


Figure 2. Mass loss course during the test

When the weight loss values measured in 300 seconds during the testing are examined, it is seen that the weight loss values of control and heat treated samples have 100%. Heat treated samples reached 100% weight loss at 198 seconds, and the control samples reached at 318 seconds. The control and heat-treated samples showed no resistance to burning; on the contrary, they seem to facilitate the burning of the wood and reach a maximum loss of weight in a short time. However, with boron usage, resistance to burning has increased at a significant level. At the end of 360 seconds, 2.5% and 5% boron impregnated specimens presented 70.71% and 39.05% weight loss respectively. In the study, the resistance of the heat-treated samples to combustion was increased and their weight loss values were reduced with the boric acid pretreatment. At the end of the time, the weight loss values for the heat-treated samples with 2.5% boron pre-impregnation were 82.48%, whereas the weight loss was 52.24% for the 5% boron pre-impregnated samples. In these variations, maximum weight loss values were reached in the short period of 100 s. Studies in the literature have shown that boron material significantly increases the fire resistance of wood (Yalınkılıç et al., 1997; Baysal, 2002). Another study on increasing the combustion performance of chip board revealed that there was a mass loss of 21.58% with the use of 12% boric acid (BA) (İstek and Özlüsoylu, 2016).

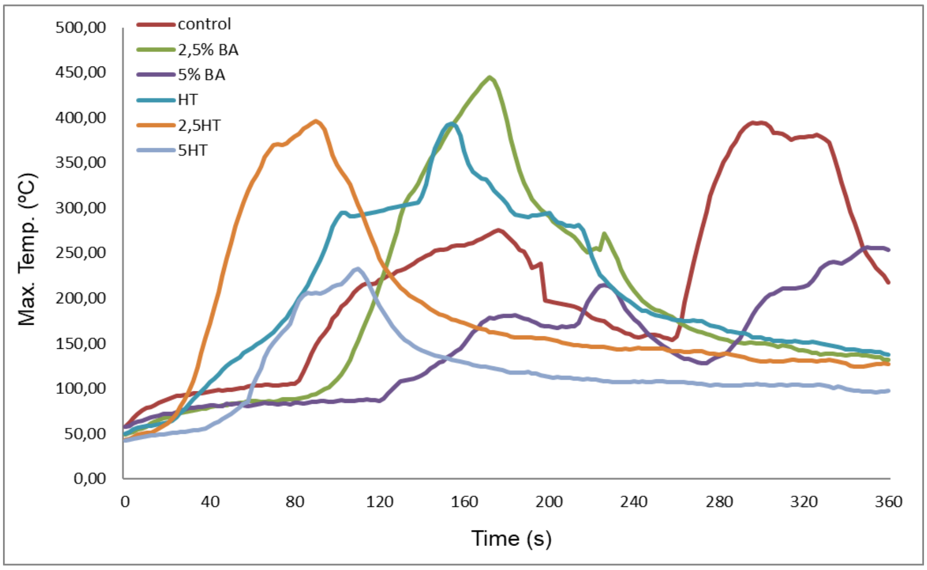


Figure 3. Maximum temperature of wood during the test

Figure 3 shows the maximum temperature values reached during the testing. The control samples took quite a long time (300 s) to reach the maximum temperature (394.65 °C); however, the samples subjected to 2.5% BA and 2.5% BA + heat treatment reached the maximum temperature in a shorter time. Samples subjected only to heat treatment reached 351 °C in 152 s, while the temperature values of these samples decreased significantly in later periods. The loss of weight values given in Figure 2 related to the maximum temperatures of the samples. That is, the maximum temperature was reached during burning in 2.5% boron pre-impregnated samples in a short time (92 s). However, the temperature values of these samples decreased significantly in the following periods. The specimens impregnated with 2.5% BA were removed after 174 seconds from the start of combustion and reached maximum temperature to 441.35 °C. Maximum temperature levels of 227 ° C and 215 ° C were obtained in 5% BA and 5% BA + heat treatment samples respectively.

Boric acid is generally incorporated in fire-inhibiting or retarding impregnation solutions in amounts ranging from 15 to 40% kg/$m^3$. Boric acid-borax mixtures are also used (Kartal and Imamura, 2004; Tomak, 2011). Borax prevents the spread of the flame. Therefore, the use of boric acid and borax together is considered to give better resistance to burning. Fogel and Lloyd (2002) stated that 15-25% by weight boric acid and/or borax must be present in the wood for good efficacy by combustion standards.

## 4. Conclusion

In the burning test, the samples subjected only to heat treatment showed a weight loss of 100% in a short amount of time, while the boron pretreated samples showed increased combustion resistance. Boron has been shown to decrease the combustion rate of heat-treated wood, with the best performance being obtained with 5%boric acid + heat treatment.

It is recommended that different boron compounds and/or mixtures of different boron compounds be tested in future studies. Additionally, different heat treatment times and temperatures should be applied.

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