# Some combustion parameters of wood impregnated with borates

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**Abstract**

This study was conducted to determine some of the combustion parameters of Calabrian pine and Oriental beech treated with borates. Average mass loss and temperature values of Calabrian pine and Oriental beech wood were determined according to ASTM E-69. Boric acid, borax, and sodium perborate were used as borates. Before the combustion test, wood specimens were impregnated with aqueous solutions (1%, 2%, 3%, 4%, 5%, and 6%) of borates according to ASTM D1413-76. These results showed that mass loss and temperature values of both wood specimens treated with borates were lower compared to the untreated control specimens. Higher concentration levels of borates resulted in lower mass loss and temperature values of the wood.

Wood and wood-based materials are combustible because they are composed primarily of organic compounds (Kollman and Cote 1968). For ignition, an oxygen flame source and flammable materials are necessary. Wood, however, has excellent natural fire resistance due to its low thermal conductivity. Charring is formed when wood is burned. In order to reduce flammability and provide safety, wood is treated with fire-retardant chemicals (Nussbaum 1988, Ellis and Rowell 1989, Mitchell 1993). The most commonly used fire-retardant chemicals in the wood industry are inorganic salts and include ammonium and diammonium phosphate, ammonium chloride, ammonium sulfate, borax, boric acid, phosphoric acid, and zinc chloride (Woo and Schniewind 1987). Boron compounds are recognized as inexpensive, easily applicable, biologically active, flame retardant and, more importantly, environmentally safe preservatives and have been used for timber preservation since the early 20th century (Williams 1990, Lloyd 1993, Laks and Manning 1994). Boron compounds containing chemicals such as boric acid and borax are commonly found in many applications in the wood preservation industry (Baysal 1994, Hafizoglu et al. 1994).

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 (LeVan and Tran 1990, LeVan and Winandy 1990). LeVan and Winandy (1990) reported that boric acid and borax have different effects on flame retardancy, as borax lengthens the time of glowing and boric acid suppresses some generation. Baysal (1994) reported that the mass loss of Calabrian pine and Oriental beech wood treated with boric acid and borax mixture were decreased compared to untreated wood specimens. Lee et al. (1989) determined oxygen index levels of three-ply, meranti plywood treated with some fire retardants. The oxygen index levels obtained were 28.4 for ammonium sulfate, 26.7 for monoammonium phosphate, 43.4 for diammonium phosphate, 30.1 for borax–boric acid, and 32.4 for minalith. Baysal (2002) studied the oxygen index levels and thermal properties of Scots pine impregnated with boron and melamine formaldehyde (MF) combinations. He found almost all of the MF-boron combinations reduced the decomposition temperature to lower levels than untreated wood. Baysal et al. (2007) reported that the lowest mass loss and temperature values of Douglas-fir were obtained on wood samples treated with a mixture of boric acid and borax after the combustion test. Ozcifci et al. (2007) investigated the fire properties of laminated veneer lumber (LVL) prepared from beech (*Fagus orientalis* Lipsky) veneers treated with some fire retardants.

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This paper was received for publication in November 2008. Article No. 10546.

Forest Prod. J. 59(6):85–89.

They found that the lowest temperature and mass loss were obtained for specimens treated with diammonium phosphate and boric acid–borax mixture.

The purpose of this study was to determine the effects of different concentration levels of borates on mass loss and temperature values of Oriental beech and Calabrian pine wood specimens after a combustion test.

## Materials and methods

### Preparation of test specimens and chemicals

Wood specimens measuring 19 (tangential) by 9 (radial) by 1016 (longitudinal) mm were prepared from air-dried sapwood of Calabrian pine (*Pinus brutia* Ten.) and Oriental beech (*Fagus orientalis* L.). Aqueous solutions of boric acid, borax, and sodium perborate were dissolved in distilled water to concentrations of 1 percent, 2 percent, 3 percent, 4 percent, 5 percent, and 6 percent. Wood specimens were oven-dried at 103° ± 2°C before and after treatment.

### Impregnation methods

Wood specimens were impregnated with aqueous solutions of borates according to ASTM D 1413-76 (ASTM 1976). Retention of boron was calculated from the equation:

$$\text{Retention } (\text{kg}/\text{m}^3) = \frac{G \times C}{V} \times 10 \qquad [1]$$

where:

$G$ = amount of solution absorbed by wood that is calculated by $T_2 - T_1$,
$T_2$ = weight of wood after impregnation,
$T_1$ = weight of wood before impregnation,
$C$ = solution concentration as percentage, and
$V$ = volume of the specimen as $cm^3$.

### Combustion test

The combustion test was performed according to ASTM E-69 (ASTM 1975). Butane gas was used to make the ignition flame. The gas flow was kept standard with the flame 25 cm high, and the temperature was held at 1000°C. Before the combustion test, wood specimens had been conditioned at 20°C and 60 percent relative humidity (RH) for 6 weeks. During the test, mass loss and temperature values were measured every 30 seconds. Average mass loss and temperature readings were obtained 10 minutes after the flame source was taken away.

### Evaluations of fire test results

Combustion test results were evaluated by a computerized statistical program composed of analysis of variance (ANOVA) and following Duncan's test at the 95 percent confidence level. Statistical evaluations were made on homogeneity groups, of which different letters reflected statistical significance.

## Results

### Mass loss and temperature values of Oriental beech wood

Average mass loss and temperature values of Oriental beech wood specimens after the combustion test are given in **Table 1**. Mass loss values of untreated Oriental beech wood were higher compared to borate-treated wood. In order to determine the effects of borates and their concentrations on mass loss and temperature values, ANOVA tests were conducted and homogeneity groups were determined by using SPSS statistical software package (**Tables 2 and 3**). The lowest mass loss obtained was 48.36 gr for Oriental beech treated with 6 percent boric acid. The highest mass loss obtained was 77.14 gr for untreated wood. Results showed that borate treatments decreased the mass loss of wood compared to the untreated control wood. The effect of borates on mass loss is given in **Table 2**. The mass loss of wood treated with borax was the lowest followed by boric acid and sodium perborate treatments, respectively. There was a statistical difference in the mass loss value between the untreated wood and the borate-treated wood. The effect of borate concentration on mass loss is given in **Table 3**. There was a statistical difference in the mass loss value

*Table 1. — Average mass loss and temperature values of Oriental beech after combustion test.*[a]

| Borates | Concentration | Retention | Mass loss | Temperature |
|---|---|---|---|---|
| | (%) | ($kg/m^3$) | (gr) | (°C) |
| Boric acid | Untreated | – | 77.14 | 293 |
| | 1 | 6.58 | 76.12 | 256 |
| | 2 | 10.97 | 75.22 | 250 |
| | 3 | 15.75 | 70.45 | 245 |
| | 4 | 22.29 | 67.98 | 233 |
| | 5 | 28.20 | 63.37 | 219 |
| | 6 | 33.73 | 48.36 | 170 |
| Sodium perborate | Untreated | – | 77.14 | 293 |
| | 1 | 5.81 | 75.51 | 213 |
| | 2 | 11.16 | 73.91 | 204 |
| | 3 | 15.05 | 70.96 | 200 |
| | 4 | 19.14 | 70.30 | 196 |
| | 5 | 22.33 | 69.41 | 176 |
| | 6 | 26.14 | 61.83 | 176 |
| Borax | Untreated | – | 77.14 | 293 |
| | 1 | 6.47 | 71.13 | 225 |
| | 2 | 13.14 | 65.74 | 215 |
| | 3 | 17.41 | 64.12 | 214 |
| | 4 | 23.15 | 60.31 | 213 |
| | 5 | 28.41 | 57.91 | 200 |
| | 6 | 32.98 | 54.58 | 180 |

[a] Results reflect the observations of five wood specimens.

*Table 2. — Duncan's test results of borates on average mass loss and temperature values of Oriental beech after combustion test.*[a]

| | Mass loss | | Temperature | |
|---|---|---|---|---|
| Borates | Mean | Homogeneity groups | Mean | Homogeneity groups |
| | (gr) | | (°C) | |
| Borax | 62.29 | A | 207 | A |
| Boric acid | 66.91 | AB | 228 | B |
| Sodium perborate | 70.32 | B | 194 | A |
| Control (untreated) | 77.14 | C | 293 | C |

[a] Similar letters reflect statistical insignificance at the 95% confidence level.

*Table 3. — Duncan's test results of concentrations of borates on average mass loss and temperature values of Oriental beech after the combustion test.*[a]

| | Mass loss | | Temperature | |
|---|---|---|---|---|
| Concentration | Mean | Homogeneity groups | Mean | Homogeneity groups |
| | (gr) | | (°C) | |
| Control (untreated) | 77.14 | E | 293 | C |
| 1 | 74.25 | D | 231 | B |
| 2 | 71.62 | CD | 223 | B |
| 3 | 68.51 | C | 220 | B |
| 4 | 66.19 | B | 214 | B |
| 5 | 63.56 | AB | 198 | AB |
| 6 | 54.92 | A | 175 | A |

[a] Similar letters reflect the statistical insignificance at the 95% confidence level.

between untreated wood and wood treated with all of the borate concentrations.

The effects of borates on temperature values of Oriental beech are given in **Table 2**. There was a statistical difference between untreated wood and borate-treated wood. Temperature values of wood were the lowest for sodium perborate, borax, and boric acid treatments, respectively. No statistical difference, however, was found between borax and sodium perborate-treated wood. **Table 3** shows the effect of concentrations of borates on temperature values of Oriental beech. There were statistical differences in the temperature values of the untreated wood and wood treated with all of the concentrations of borates. With the exception of the 6 percent concentration of borates, there were no statistical differences among all of the concentration levels of borates.

### Mass loss and temperature values of Calabrian pine wood

Average mass loss and temperature values of Calabrian pine wood specimens are given in **Table 4**. Mass loss value of untreated Calabrian pine wood was higher compared to borate-treated wood. In order to determine the effects of borates and their concentrations on mass loss and temperature values, ANOVA tests were conducted and homogeneity groups were determined by using SPSS statistical software package (**Tables 5 and 6**). The lowest mass loss obtained was 55.85 gr for Calabrian pine treated with 6 percent borax. The highest mass loss obtained was 92.46 gr for untreated Calabrian pine wood. Results showed that boron treatments decreased the mass loss of wood compared to the untreated control. The effect of borates on mass loss is given in **Table 5**. Mass loss of wood treated with boric acid was the lowest followed by sodium perborate and borax treatments, respectively. There was a statistical difference in the mass loss value between untreated wood and borate-treated wood. But, no statistical differences were found between boric acid, sodium perborate, and borax treatments. The effect of borate concentrations on mass loss is given in **Table 6**. There was a statistical difference in the mass loss value between the untreated wood and wood treated with all of the borate concentrations. The effects of borates on temperature values of Calabrian pine wood are given in **Table 5**. There was a statistical difference in the temperature value between untreated and borate-treated wood. Borate treatment significantly reduced the temperature values of wood compared to untreated wood. Temperature values of wood treated with borax were the lowest followed by boric acid and sodium perborate treatments, respectively. **Table 6** shows the effects of concentrations of borates on temperature values of wood. The temperature values of untreated wood were higher compared to borate-treated wood. With the exception of the 1 percent treatment, all of the borate concentrations significantly lowered the temperature values of Calabrian pine.

*Table 4. — Average mass loss and temperature values of Calabrian pine after combustion test.*[a]

| Borates | Concentration | Retention | Mass loss | Temperature |
|---|---|---|---|---|
| | (%) | (kg/m$^3$) | (gr) | (°C) |
| Borax | Untreated | – | 92.46 | 360 |
| | 1 | 5.66 | 92.01 | 267 |
| | 2 | 12.53 | 89.20 | 263 |
| | 3 | 17.54 | 85.10 | 196 |
| | 4 | 25.33 | 78.26 | 189 |
| | 5 | 31.42 | 70.05 | 172 |
| | 6 | 35.50 | 55.85 | 158 |
| Sodium perborate | Untreated | – | 92.46 | 360 |
| | 1 | 4.71 | 85.30 | 279 |
| | 2 | 10.28 | 82.23 | 269 |
| | 3 | 18.71 | 79.75 | 261 |
| | 4 | 23.15 | 76.27 | 241 |
| | 5 | 27.64 | 72.71 | 226 |
| | 6 | 30.53 | 66.63 | 220 |
| Boric acid | Untreated | – | 92.46 | 360 |
| | 1 | 5.13 | 85.40 | 266 |
| | 2 | 9.47 | 79.98 | 265 |
| | 3 | 17.68 | 77.45 | 249 |
| | 4 | 26.66 | 77.32 | 243 |
| | 5 | 33.13 | 62.75 | 195 |
| | 6 | 37.42 | 57.24 | 182 |

[a] Results reflect the observations of five wood specimens.

*Table 5. — Duncan's test results of borates on average mass loss and temperature values of Calabrian pine after the combustion test.*[a]

| | Mass loss | | Temperature | |
|---|---|---|---|---|
| Borates | Mean | Homogeneity groups | Mean | Homogeneity groups |
| | (gr) | | (°C) | |
| Borax | 78.41 | A | 208 | A |
| Sodium perborate | 77.14 | A | 249 | B |
| Boric acid | 73.35 | A | 233 | B |
| Control (untreated) | 92.46 | B | 360 | C |

[a] Similar letters reflect the statistical insignificance at the 95% confidence level.

## Discussion

Retention levels of Oriental beech and Calabrian pine wood specimens were 5.81 to 33.73 kg/m$^3$ and 4.71 to 37.41 kg/m$^3$, respectively. As the borate concentration levels increased, retention levels in the wood increased. Concentration levels

*Table 6. — Duncan's test results of concentrations of borates on average mass loss and temperature values of Calabrian pine after the combustion test.*[a]

| Concentration | Mass loss | | Temperature | |
|---|---|---|---|---|
| | Mean | Homogeneity groups | Mean | Homogeneity groups |
| | (gr) | | (°C) | |
| Control (untreated) | 92.46 | F | 360 | D |
| 1 | 87.57 | E | 271 | D |
| 2 | 83.80 | D | 266 | C |
| 3 | 80.86 | C | 235 | C |
| 4 | 77.28 | C | 224 | B |
| 5 | 68.50 | B | 198 | B |
| 6 | 59.90 | A | 186 | A |

[a] Similar letters reflect the statistical insignificance at the 95% confidence level.

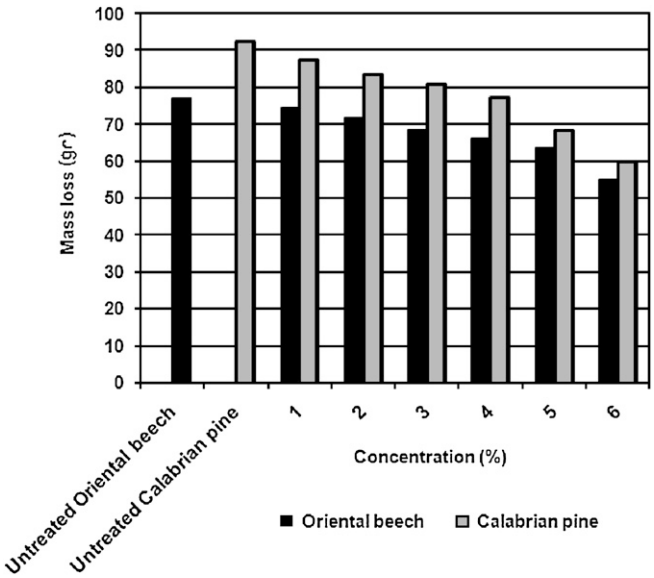


*Figure 1. — Average mass loss of Oriental beech and Calabrian pine related to borate concentration levels.*

of borates related to mass loss and temperature profiles for both wood species after the combustion test are shown in **Figures 1 and 2**, respectively. These results showed that higher concentration levels of borates produce lower temperature values and mass loss of wood. Grexa and Lübke (2001) investigated the effect of different loads of magnesium hydroxide as a flame retardant on the flammability parameters of particleboard. They found that increasing the amount of magnesium hydroxide significantly improved the overall fire behavior of particleboard. Also, White (1979) noted that the oxygen index levels increased with an increase in the treatment level of chemicals. The results of this study are consistent with these findings. Tsai and Wang (1991) noted that the incombustibility of untreated substrates was directly proportional to their specific gravity. Kanury (1972), and Matson et al. (1959) reported that the temperature of ignition is influenced by many factors related to the wood under thermal exposure and conditions of its environment. Factors include species, density, moisture content, thickness, surface area, surface absorbtivity, pyrolysis characteristics, thermoconductivity,

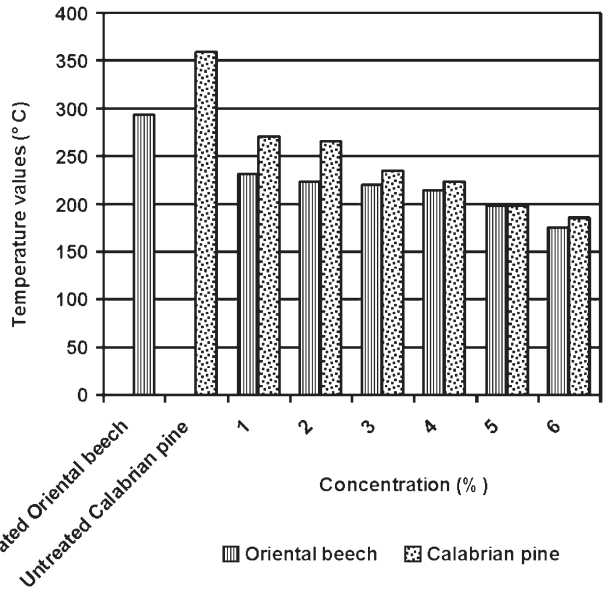


*Figure 2. — Average temperature values of Oriental beech and Calabrian pine related to boron concentration levels.*

specific heat, and extractive content. In this study, in general, temperature values and mass loss of untreated and treated Oriental beech wood specimens were lower than untreated and treated Calabrian pine wood specimens after the combustion test.

## Conclusion

In this study, mass loss and temperature values of Oriental beech and Calabrian pine treated with waterborne solutions of (1%, 2%, 3%, 4%, 5%, and 6%) sodium perborate, boric acid, and borax were evaluated. Average mass loss and temperature values of untreated wood were higher than those of treated wood. These results showed that borate treatments significantly reduced the average mass loss and temperature values of both wood specimens. The higher concentration levels of borates resulted in lower temperature values of wood.

In conclusion, the results of this study indicated that Calabrian pine and Oriental beech wood impregnated with boron compounds have enhanced combustion parameters such as mass loss and temperature values. They caused lower mass loss and temperature values of treated wood than untreated wood.

## Acknowledgment

This work is supported by the State Planning Organization of Turkish Prime Ministry Award 2003 K120850.

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