Improving Fire Resistance of Mahogany (*Swietenia macrophylla*) Wood Impregnated with Mixture of Borax and Boric Acid

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Abstract

The study was aimed to investigate the effects of mixture of borax and boric acid concentration and different level of pressure on absorption, retention quantity, and fire resistance properties of mahogany (*Swietenia macrophylla*). A total of 50 samples of 9 x 19 x 1016 mm (ASTM E 69-02) were taken from mahogany lumber and then air-dried. A total of 45 samples were impregnated with aqueous solutions of borax and boric acid in three different concentrations (5, 7, and 9 %) and at three different pressure levels (5, 7.5, and 10 atm) for 2 hours pressure time, while 5 samples were lifted as control. Dried impregnated samples and untreated samples were feeding in flame with lid combustion method refers to ASTM E 69-02. Interestingly, the results showed that borax and boric acid effectively improved the fire resistance properties (mass losses, ignition temperature, maximum temperature, and smoke and smolder production) of mahogany wood. Mixtures of borax and boric acid at a concentration level of 9% and pressure of 10 atm are recommended to obtain the best results compare to the other interactions on combustion properties.

Keywords: Borax, boric acid, impregnation, mahogany-wood, fire resistance

Introduction

Improving wood fire resistance has been an important aspect as wood, which is carbon-based cellulosic materials, tends to be combusted when subjected to heat at 270°C or with flammable materials at a lower temperature. Combustion of wooden materials is usually in the later stage of the fire but becomes more critical due to its proportion and position in building construction, especially in heavy timber construction. To improve safety, Inflammable wooden materials have been developed to reduce ignition and combustion properties. Fire retardant chemicals have been proposed and used to reduce the ignitability and combustibility of wood (Östman 2017). The pressure impregnation method has been widely suggested to increase adequate retention.

Boron components have been widely added as a booster to a fire-retardant compound to improve the effectiveness (Yu *et.al*. 2017a). Several studies have been conducted to investigate the effect of boron compounds on the fire resistance of wood. Recently, boron has been designated to be applied as a fire retardant for indoor wood furniture and other materials due to several advantages. Borax is one of the water-borne fire retardants which have several advantages such as against wood-destroying organism, reduce the flame spread, low eco-toxicity, and low volatility, colorless, odorless, and reasonable price (Winandy 1977; Yamaguchi 2001; Akbulut *et al*. 2004; Baysal and Yalinkilic 2005). However, borax has a disadvantage, which can promote glowing or smoldering. On the other hand, boric acid could reduce glowing and smoldering. There are no single chemicals normally used in fire retardants. Therefore boron-based buffers are important to be tested in fire-retardant treatments to significantly reduce the severity of thermal degradation of commercial wood in Indonesia.

Mahogany (*Swietenia macrophylla*) is one of the highest commercially tropical timbers used, especially in Indonesia due to well-fast growth, specific gravity (0.61), and well machining properties (Martawijaya *et al*. 1989; Listyantp *et al.* 2016). However, it shows a lower durability class and resistant to fire. It is important to improve durability and fire resistance at the same time.

Wood impregnation process is influenced by several factors, both internal and external. Numerous important external factors are affecting the rate of impregnation such as the level of pressure, the composition and concentration of the impregnating solution, temperature, and, the time required for treatment. Impregnating solution contains boron components to mahogany wood are attracted to be studied. A proportion of borax and boric acid (1:1 w/w) with a concentration of 20% showing excellent results on fire-retardant properties on bamboo filament (Yu *et al*. 2017b). This study aimed to investigate the effect of interaction between three different concentrations (5, 7, and 9 %) and at three different pressure levels (5, 7.5, and 10 atm) for 2 hours pressure time on absorption, retention, mass losses, and combustion properties of mahogany wood. Observation of characteristic of thermal degradation is also essential as wood does not directly burn. Initial glowing point and flammable point of wood are observed concerning thermal conductivity and impregnated chemicals.

Materials and Methods

Materials

Research materials were mahogany lumber harvested at 25 years-old. A total of 50 samples of 9 x 19 x 1016 mm (radial by tangential by longitudinal) (ASTM E 69-02) were taken from a mahogany board and then air-dried. Three groups concentration of borate, an aqueous solution of borax and boric acid mixed by weight (1.54/1; w/w) and dissolved in distillate water to a concentration 5%, 7%, and 9%, were prepared one day before treatment. For example, a volume of 30 liters aqueous borate 5% was made by mixing 1.5 liters borate and 28.5 liters distillate water.

Method

The samples were impregnated with aqueous solutions of borax and boric acid in three different pressure levels; 5 atm, 7.5, atm, and 10 atm for 2 hours pressure time. Five replicates were used for each treatment variation. Five samples were lifted untreated as a control. The air-dried sample was observed on absorption (%, w/w), and retention (%, w/w). Samples were tested by feeding to the flames for four minutes with lid combustion method refers to ASTM E 69-02. Analysis of variance and Tukey Honestly Significant Difference test at the 95% confidence level were conducted to perform statistical analysis.

Results and Discussion

Absorption and Retention

The absorption of treated samples was in the range of 197-356 kg/m^3 (Fig. 1). The retention was in the range between 9.85 kg/m^3 and 31.5 kg/m^3. The results showed that no significant difference ($p<0.05$) was found in absorption and retention quantity. Pressure impregnation at 5, 7, and 9 atm, showed adequate effectiveness to increase retention quantity. Retention of borate solution is higher than that of prescribed in AWPA (2010) for timber foundation or structure in a hazardous condition. Therefore impregnating borate solution with a concentration of 5-9% with pressure level 5,6, and 9 atm meet with the standard (AWPA 2010).

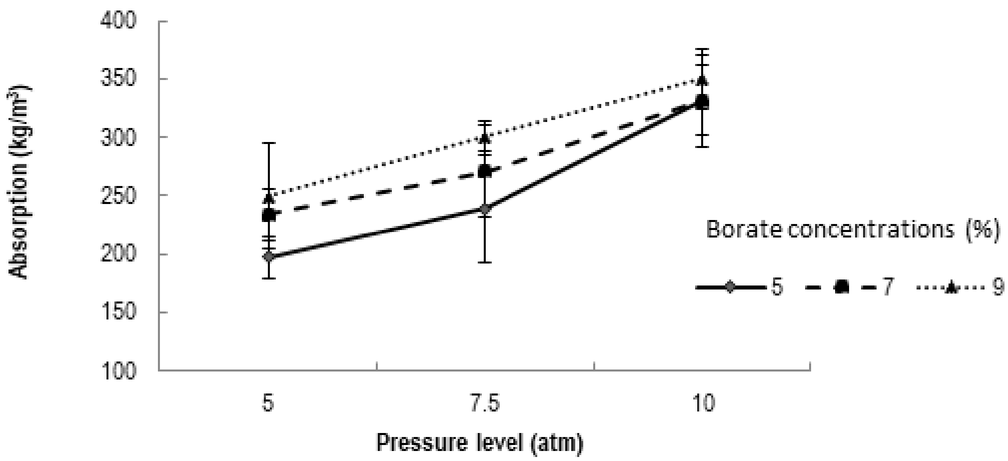

Figure 1. Graphic of Absorption (kg/m^3) of treated samples in different concentration of borate (5, 7, and 9%) and different pressure (5, 7.5, and 10 atm).

Mass Losses

Interestingly, during the fire resistance test, mass losses decreased significantly ($p<0.05$) in the treated samples (6.31%) compare to control (83%), as shown in Fig. 2. This result indicates that borax and boric acid are effective in increasing the fire resistance of mahogany lumber. This inline with the study of Awoyemi and Westermark (2005) that boron-based buffers can be used in fire-retardant treatments and have been found to significantly reduce the severity of thermal degradation. In terms of physical mechanism, boron components effectively form a protective layer on the wood surface to avoid fire (Kandola *et al*. 1996). In terms of chemical mechanism, boric acid seemed to successfully catalyze the dehydration and other oxygen-eliminating reactions of wood at a relatively low temperature, which contributes partly to the effects of boric acid for promoting charring and fire retardation of wood (Wang *et al*. 2004). However, there was no significant difference ($p<0.05$) in mass losses among treatments. Therefore, borate centration 5% and pressure level 5 atm is sufficient to avoid mass losses during the fire retardant process on mahogany wood.

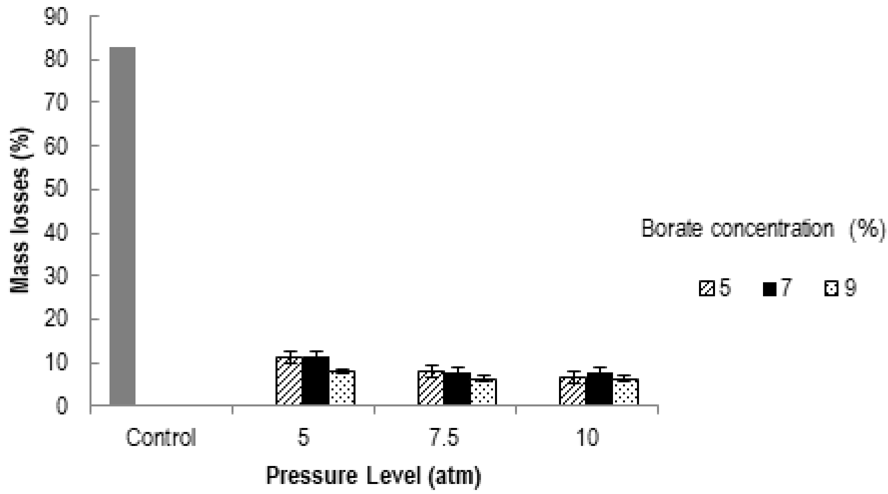

Figure 2. Graphic of mass losses (%) of treated samples in different concentration of borate (5, 7, and 9%) and different pressure (5, 7.5, and 10 atm), and control.

Combustion Properties

Combustion properties of the treated sample improved significantly ($p<0.05$) compared to control. The initial ignition point of treated samples was at 317°C while the control sample in 117°C (Fig. 3). The ignition point of the untreated sample was very low which cause the lumber more was to be burned. The reason is that elements of boron could create a B_2O_3 layer that spread across the surface of the wood sample to isolate oxygen and fire (Yang and Qing 2014). The result is consistent with the study by Yu *et al*. (2017b). In addition, bound water is released by boron compound caused cooling material and absorbing the heat (Marosi *et al*. 2001). The highest initial smolder point of the treated sample was found in borate concentration 9% and pressures 10 atm (457°C). Besides, the maximum combustion temperature was also significantly ($p<0.05$) decreasing for the treated sample (573°C) compare to the control (653°C) as shown in Fig. 4.

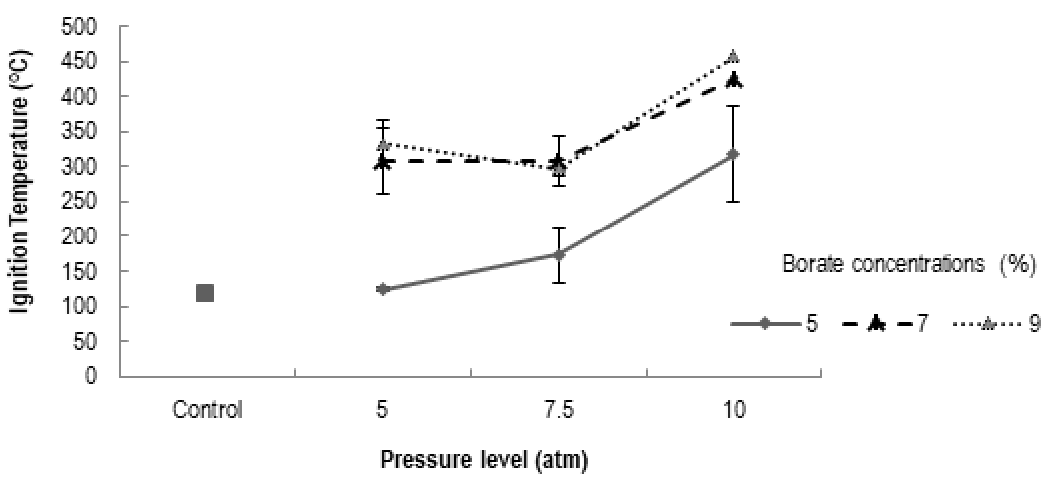

Figure 3. Graphic of Ignition temperature (°C) of treated samples in different concentration of borate (5, 7, and 9%) and different pressure (5, 7.5, and 10 atm), and control.

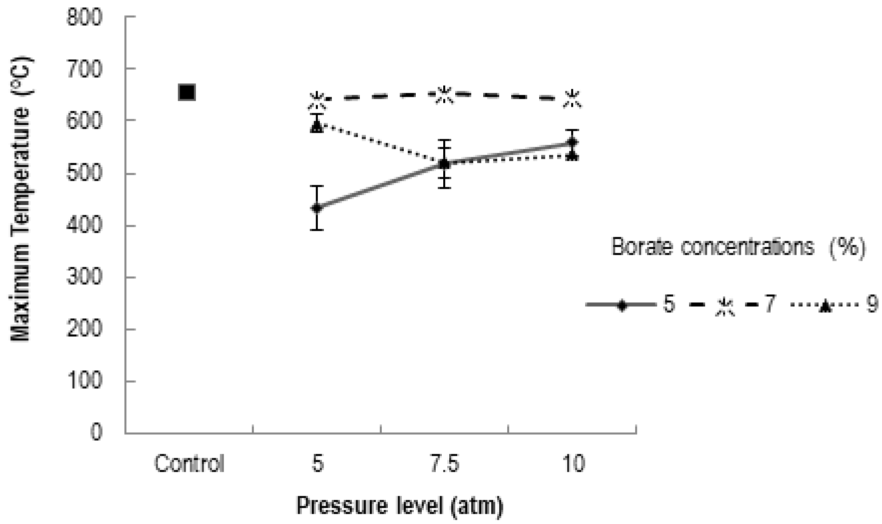

Figure 4. Graphic of maximum temperature (°C) of treated samples in different concentrations of borate (5, 7, and 9%) and different pressure (5, 7.5, and 10 atm), and control.

Visual inspection showed that the treated sample produce a slight smolder compare to the control (Table 1). Heavy smolder is an indicator that wood will be immediately burned. Boron reduces significantly smoke release and suppresses smolder. This result is corresponding to the result of research by Yu *et al*. (2017b) Therefore, the lower intensity of the smoke and smolder will be an important indicator to assess good fire retardant. Wang *et al*. (2004) proposed an explanation that mixtures of borax and boric acid could produce a char as a catalytic consequence at a lower temperature. A mixture of borax and boric acid (1:1) is an important factor in reducing smoke and smolder because borax has lower performance in suppressing smoke and smolder (Yu *et al.* 20017b)

In general, this study showed that impregnation with the combination of borax and boric acid in various concentrations and pressure showed effective improvement on fire resistance properties of mahogany. Impregnating boron components (borax and boric acid) with ratio mixing of 1:1 (w:w) at concentration level 9% and pressure 10 atm showed the best result compare to the other interactions on combustion properties. This corresponds to the study of Baysal *et al*. (2006), Yu et al. (2017b) that boric acid and borax had excellent fire-retardant effectiveness over untreated ones. This information is important because borax and boric acid could be considered wood preservative and fire retardant.

Table 1. Grade of based on visual observation

Concentration Levels [%]	Pressure [atm]	Smoke	Smolder
5%	5	medium	narrow
	7.5	medium	narrow
	10	medium	narrow
7%	5	narrow	narrow
	7.5	narrow	narrow
	10	medium	narrow
9%	5	narrow	almost none
	7.5	narrow	almost none
	10	narrow	almost none
Control		excessive	burned

Conclusions

In summary, mixture of borax and boric acid in concentrations of 6, 7, and 9% and pressure level of 5, 7.5, 10 atm showed effective improvement on fire resistance properties (mass losses, ignition temperature, maximum temperature, and smoke and smolder production) of mahogany. Impregnation with mixture of borax and boric acid at concentration level 9% and pressure 10 atm showed the best result compare to the other interactions on combustion properties.

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