EFFECT OF COMBUSTION RATE ON PHYSICAL PROPERTIES AND SURFACE APPEARANCE OF MINDI AND PINE WOOD

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2026

ABSTRACT

Naturally weathered boards are increasingly in demand as raw materials for furniture because they seem elegant and antique. Because it takes a very long time, natural weathered broads can be replaced with artificial weathered broad. This study aims to evaluate the effect of different combustion rates on the physical properties and appearance of mindi and pine wood after treatment. The combustion rate is set in two, namely 0.5 and 1.0 seconds/cm^2. The properties of the wood tested follow the standard procedure of each test parameter, while the appearance of the surface is visually observed. The results showed that the combustion rate and wood species affected moisture content (MC), density, specific gravity (SG), thickness reduction and wood appearance. Higher combustion rates result in reduced MC, density and SG of wood, while the reduction in thickness increases. In general, the artificial weathered boards can still be used as raw materials for making furniture because the surface appearance becomes more aesthetically valuable with a strong class that has not changed much.

Keywords: artificial weathering, durability, combustion rate, naturally weathered wood, physical property.

INTRODUCTION

Indonesia is one of the countries that is famous for furniture and handicrafts made of wood. Its main export markets are the United States, Japan and some European countries. Based on data issued by the Central Statistics Agency (BPS), the export value of various kinds of Indonesian furniture and wood handicraft products during 2017 reached US$ 2 billion or equivalent to Rp. 27 trillion, an increase of US$ 400 million when compared to the previous year (BPS 2018). The demand for Indonesian wooden furniture is due to its attractive, unique, elegant design, color match and competitive price (Ministry of Industry 2016). In addition to depending on design and patterns, furniture that is in particular in demand in the European and American markets is dark colors such as teak, mahogany and ebony (USAID-SENADA 2007). Unfortunately, these species are relatively slow to grow so that they can hinder export volumes and there is a possibility that the quality of the product will change due to the use of similar wood from younger stands. According to the results of previous studies, the quality of wood from younger stands is inferior in terms of strength, dimensional stability and natural durability (Wahyudi et al. 2014; Trockenbrodt and Josue 1999).

Uncoated wood exposed to weather can change color and appearance due to photolytic reactions, oxidation and also hydrolytic chemical content (Reinprecht 2016). This process is known as weathering (Tsoumis 1991). As a result of weathering, the surface of the wood will be degraded, eroded, become rougher and darker. For some reason, such a wooden appearance even has high aesthetic value because it seems antique so it is in demand as a raw material for making furniture.

Natural weathering is very slow. According to Williams (2005), 5-6 mm thick scraping on wood surfaces takes more than 100 years. Given the relatively high market opportunity for weather-exposed timber, artificial weathering techniques have been developed to produce exposed timber in a shorter period of time. One of them is the surface combustion technique. This method originating from Japan known as shou sugi ban or yakisugi was originally intended to preserve sugi (Cryptomeria japonica) wood which is commonly used as a wall cladding. In addition to being more durable, the surface appearance of sugi wood after burning becomes more unique and antique like naturally exposed wood. That is why there are currently many developments in wood surface burning techniques, especially in America (Mosenthal 2014).

The principle of combustion is to burn the surface of the wood so as to produce a layer of charcoal. The success of the process is determined by the magnitude of the temperature, the length of time and the rate of combustion applied. Research on this, especially using Indonesian wood, has never been done, especially on fast-growing wood. Considering the high demand for high-quality antique furniture from wood, the author started this study using mindi (*Azedarachta excelsa*) wood. As a comparison, the burning process is also carried out using pine (*Pinus merkusii*) wood. The main variable of the study is the length of combustion time which is approached by the value of the combustion rate. This study aims to study the effect of the difference in the length of combustion time on the physical properties and appearance of mindi and pine wood.

METHODOLOGY

Material

The main materials used are mindi and pine wood from the sawmill industry in Ciampea, Bogor, Indonesia. The equipment used consisted of heating torches, circular saws, sanders, brushes, ovens, analytical scales, calipers, Cannon 4400F scanners, thermo guns and stationery.

Test Sample Preparation

The air-dried board is cut into several test samples. Physical properties testing consisting of moisture content (MC), wood density and specific gravity (SG) was carried out referring to BS-373:1957 with samples of 2 cm × 2 cm × 2 cm, while the surface appearance test (color and condition) used test samples measuring 1.5 cm × 5 cm × 15 cm. The total samples tested were 24 for each parameter (3 treatments, 2 types and 4 replicates).

Moisture Content, Density and Specific Gravity Measurement

The value of MC, density and SG of wood is calculated by the equation:

$$\% \text{ MC} = \frac{\text{BKU} - \text{BKT}}{\text{BKT}} \times 100$$

$$\text{Density } (\rho) = \frac{\text{BKU}}{\text{VKU}}$$

$$\text{Specific gravity (SG)} = \frac{\text{BKT}}{\text{VKU}} / \rho_{\text{water}}$$

Where:

MC = Moisture content (%)
VKU = Sample volume in air dried condition (cm^3)
ρ_{water} = Density of water (g/cm^3)
BKU = Sample weight in air dried condition (g)
BKT = Sample weight in oven dried condition (g)

Surface Combustion

The length of combustion time is approached from the value of the combustion rate, where for the same test sample surface area, a higher combustion rate means a longer combustion time.

The test samples whose dimensions and MC are already known are arranged on an aluminum mount and then a fire with a temperature of ± 300 °C through a heating torch is sprayed onto one of the sample surfaces (Figure 1) with a combustion rate of 0.5 and 1.0 seconds/cm², then left to cool. After that the surface of the sample is rubbed with a brush. The clean sample is then recalculated the MC value, density and SG following the equation as above. In addition, it is also calculated that the thickness reduction is large. Checking the combustion temperature is carried out with a thermogun.

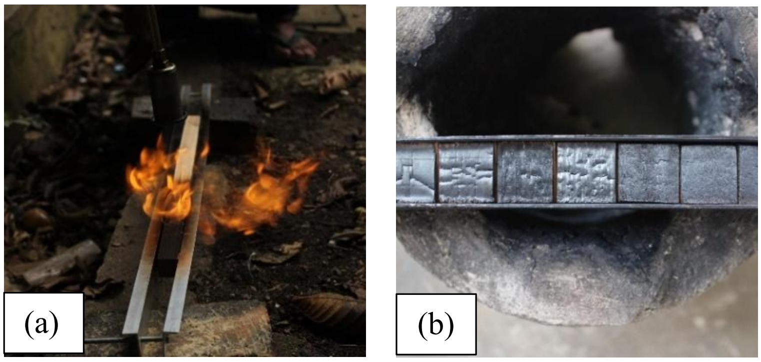

Figure 1 The burning process (a) and the test sample after burning (b).

Thickness Reduction Measurement
The reduction in the thickness of the sample surface is set as the difference in thickness before and after combustion, which is calculated by the formula:

$$\text{Thickness reduction} = \text{Innitial thickness} - \text{Final thickness}$$

Observation of the Appearance of the Wood Surface
The appearance of the wood surface including the discoloration before and after combustion is visually observed.

Data Analysis
Data were statistically processed using a 2-factor, 4-replicate Complete Random Design, at 95% confidence intervals. Factor A is the wood species (pine and mindi), while factor B is the combustion rate (0, 0.5 and 1 second/cm²). If the difference is significant, then it will be continued with the Duncan Multiple Range Test. The equation used is:

$$\mathbf{Yij = \mu + Ai + Bj + (AB)ij + \epsilon ijk}$$

Where:

Yij	=	Response value at the i-level of the wood species; while the j-level of the burning time
μ	=	General average
Ai	=	Effect of wood species on the i-level
Bj	=	Effect of combustion rate on the j-level
(AB)ij	=	Effect of the interaction of wood species on the i-th level and combustion rate on the j-th level
ϵijk	=	Errors on the i-th and the j-th treatments and the k-th repetition
i	=	Wood species (pinus and mindi)
j	=	Combustion rate (0 s/cm², 0.5 s/cm² and 1 s/cm²)
k	=	Repetition 1, 2, 3 and 4

RESULTS AND DISCUSSION

Moisture Content

The results show that the wood MC after the combustion process is lower than the control. The MC tends to decrease with the higher the combustion rate or the increase in combustion rate (Figure 3). This is strengthened by the ANOVA which shows that the length of combustion rate and the wood species have a significant effect on the MC. This result corresponds to Xian-Jun et al. (2011).

The average MC of the control mindi wood is 12.69%, while for the pine wood is 11.91%. After being burned with a combustion rate of 0.5 s/cm^2, the MC of mindi and pine wood decreased to 7.96 and 9.86%, respectively; while with a combustion rate of 1 s/cm^2 the values became 3.66 and 4.84%, respectively. Thus, it appears that a combustion rate of 1 s/cm^2 or a longer combustion time will result in a higher reduction in the value of the MC. In case of mindi wood the combustion rate of 1 s/cm^2 resulted in a reduction of 71.15%, while in pine wood it was a 59.36% reduction.

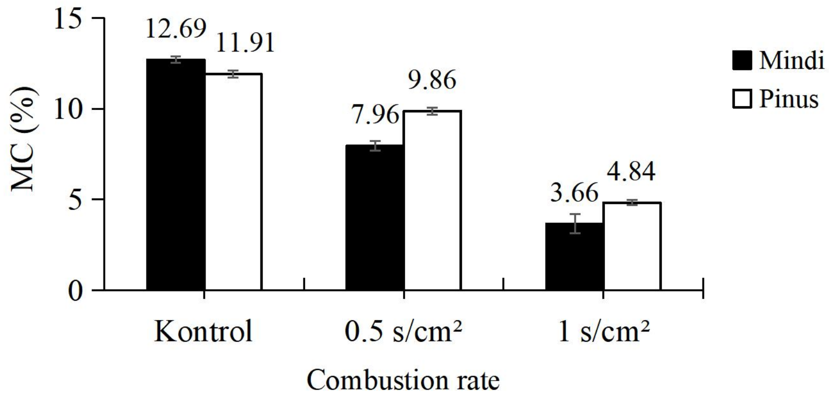

Figure 3 Average MC of mindi and pine wood at each combustion rate.

The reduced water content in the wood is due to the presence of heat used during the combustion process. According to Rowell and Dietenberger (2013), water begins to come out of the wood at a temperature of 100 ºC. At a temperature of 200 ºC, chemical bonds begin to break and volatile gases are released. In the temperature range of 200 to 300 ºC, the degradation of hemicellulose, cellulose and some lignin occurs. Further explained by Korkut et al. (2008); Kocafe et al. (2009), degradation of hemicellulose and cellulose by heat causes the existing hydroxyl group to decrease.

In the same treatment, the MC of mindi wood after burning is lower than the MC of pine wood. This is related to the difference in wood species, especially the type and condition of the pitting and the thickness of the cell wall. Aspirated pitting on the tracheid cell wall of pine wood could inhibits the escape of water. Coupled with the presence of resin. This is what results in the MC of pine wood after burning remains higher than that of mindi wood.

The lower MC of mindi wood after combustion is also related to simple pits on the cell wall. According to Panshin and de Zeeuw (1989); Bowyer et al. (2003), simple pits does not have a torus so that the movement of water is easier. The presence of heat results in more water coming out.

Specific Gravity and Wood Density

The results show that the SG of wood after the combustion process is also lower than that of the control wood. The SG tends to decrease with the longer the burning time (Figure 4). This is reinforced by ANOVA which shows that the length of burning time and the wood species have a very significant effect on the SG value.

The average SG of mindi wood is 0.53, while the SG of pine wood is 0.49. After burning with a burning rate of 0.5 s/cm^2, the SG of mindi and pine wood was reduced to 0.49 and 0.43 respectively; while with a combustion rate of 1 s/cm^2 the value became 0.47 and 0.42 respectively. Compared to the control SG, the combustion rate of 1 s/cm^2 resulted in a reduction in the SG of mindi wood by 11.32%, while in pine wood it was 14.28%. Fortunately, the reduction in the SG value of the wood did not change its strong class.

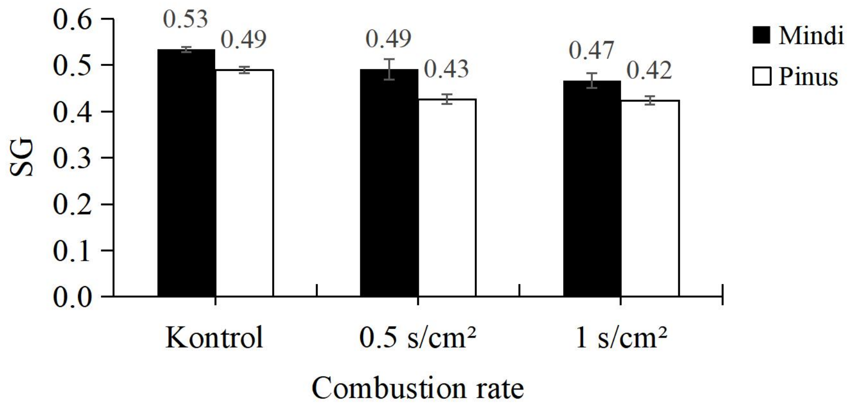

Figure 4 Average SG of mindi and pine wood at each combustion rate.

In terms of wood density, the results showed that the density of wood after the combustion process was also lower than the control one. Wood density tends to decrease with increasing combustion time (Figure 5). This is also strengthened with its ANOVA.

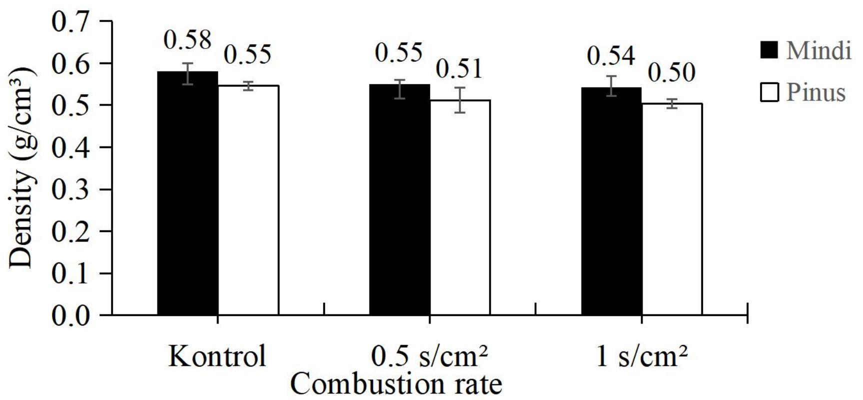

Figure 5 Average density of mindi and pine wood at each combustion rate.

The average density of control mindi wood was 0.58 g/cm^3, while the density of control pine wood was 0.55 g/cm^3. After burning with a burning rate of 0.5 s/cm^2, the density of mindi and pine wood decreased, to 0.55 and 0.51 g/cm^3, respectively; while with a burning rate of 1 s/cm^2 the values became 0.54 and 0.50 g/cm^3, respectively. Thus the longer combustion time also results in a greater reduction in density value. The combustion rate of 1 s/cm^2 resulted in an 8.62% reduction in the density of mindi wood compared to the control, while pine wood was reduced by 9.09%.

According to Hill (2006); Gokhan and Denis (2009), heat treatment on wood causes the degradation of hemicellulose, cellulose and lignin so that SG and density of wood are reduced. The reduction of SG and density after combustion is evidenced by the presence of a layer of charcoal formed on the surface of the sample. According to Reinprecht (2016), the density of the charcoal layer is only 20% of the density of the wood. The reduction in SG and wood density value was also related to the low reduction in sample thickness after the process compared to the reduction in weight.

Thickness Reduction

The measurement results show that the combustion process results in a difference in thickness reduction values. The thickness reduction increases as the combustion rate increases (Figure 6). This is reinforced with its ANOVA. Duncan's further test results showed that the combustion rates were 0.5 and 1.0 s/cm^2, both of which were significantly different.

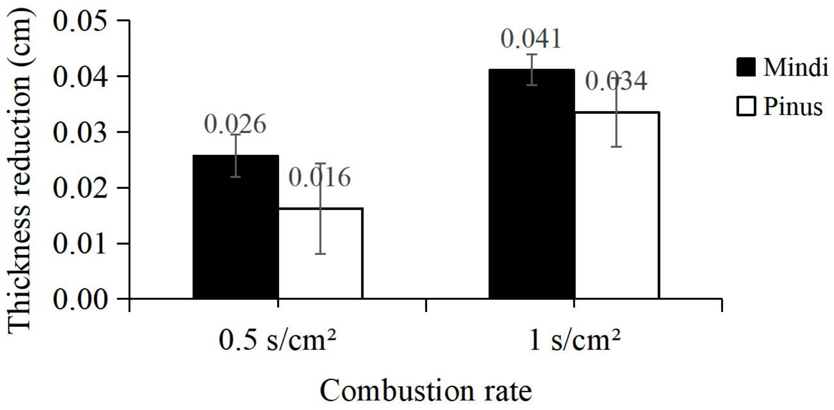

Figure 6 Average thickness reduction of mindi and pine wood at each combustion rate.

With a burning rate of 0.5 s/cm^2, the average reduction in the thickness of mindi wood is 0.026 cm, while pine wood is 0.016 cm. On the other hand, with a combustion rate of 1 s/cm^2, these values are 0.041 and 0.034 cm, respectively. Thus it can be said that a longer of combustion time will result in a greater reduction in thickness. At 1 s/cm^2 burning, there was a reduction in thickness in mindi wood by 57.69% compared to 0.5 s/cm^2, while in pine wood by 112.50%.

The thickness reduction due to the combustion process is determined by the difference in the rate of degradation of the chemical components that make up the cell wall (Achmadi 1990) and the rate of combustion that occurs (White and Nordheim 1992). The difference in degradation rate is influenced by the different types of monomers that make up the chemical components of the cell wall, especially hemicellulose and lignin.

According to Achmadi (1990), hemicellulose and lignin of hardwoods are different compared to those in conifer (softwoods). Mindi wood hemicellulose is composed of glucomannan and glucoronoxylan, while pine wood hemicellulose is composed of galactoglucomannan, arabinoglucoronoxylan and arabinogalactane. Mindi wood lignin consists of guaiasil-siringil, while pine wood lignin is dominated by guaiasil. According to White and Nordheim (1992), the rate of combustion is influenced by the density and thickness of the wood, chemical composition, thermal conduction and gas permeability.

Surface Appearance

The appearance of mindi wood before and after the burning process is presented in Figure 7, while pine wood Figure 8. Visual observations show that the combustion process results in a change in the surface appearance of both wood species. Compared to the control, the wood becomes darker and rougher, with a charred surface.

The appearance of the wood surface is affected by the length of the burning time and the wood species. The longer the time, the darker, rougher and more cracked the surface. Compared to pine wood, the longer the mindi wood is burned, the darker the surface, but the roughness and cracking of the charcoal is less. A burning rate of 0.5 s/cm^2 in pine wood results in a better appearance compared to a long burning rate due to the presence of growth rings.

According to Rowell and Dietenberger (2013), heat treatment with a temperature of 300 °C results in the formation of charcoal on the surface of the wood. The formed charcoal layer is able to inhibit the subsequent degradation so that it can function as a fire retardant agent (White and Dietenberger 2010).

Figure 7 Appearance of mindi wood surface before and after burning.

Figure 8 Appearance of pine wood surface before and after burning.

Compared to the surface of pine wood that was exposed to natural exposure for 33 months (Figure 9), the treatment applied in this study has the potential to be developed because with a shorter time it is able to produce the wood with a not much different appearance.

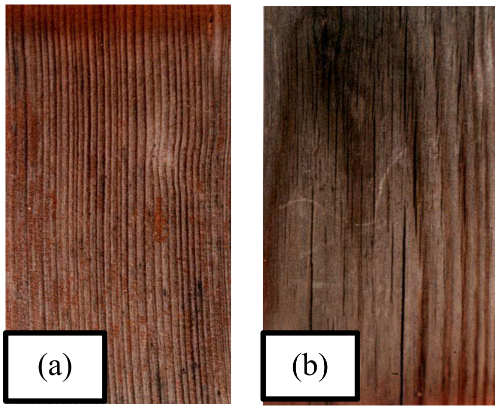

Figure 9 Surface view of pine wood after 33 months of natural exposure: (a) radial plane and (b) tangential plane (Source: Sandberg 1999).

CONCLUSION

The results showed that the combustion rate and wood species affected the MC, density, SG, thickness reduction and wood appearance. Higher combustion rates result in reduced MC, density and SG of wood, while thickness reductions increase. In general, the wood from burning can still be used as raw materials for making furniture because its surface becomes more aesthetic and the strong class of wood does not change significantly.

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