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EFFECT OF THERMAL TREATMENT ON SELECTED FIRE SAFETY FEATURES OF TROPICAL WOOD

The subject matter of the article is thermally modified tropical wood (Meranti and Merbau) and its reaction on fire. Thermal treatment of wood (thermal wood) is a new technology of wood treatment improving its physical and biological properties and increasing its resistance to biological wood destroying processes and atmospheric effects. The fire and technical properties of thermal wood, especially its reaction to fire, have not been studied sufficiently. The latter is the subject matter of this article. A comparison is made to describe the influence of process temperatures of the thermal modification of selected tropical woody plants. Experimental equipment was non-standardized laboratory equipment using a flame source of higher intensity (flame burner - propane-butane) affecting the test sample in an open environment. This is a simulation of an actual fire. The performance of the thermally treated wood (20 °C, 160 °C, 180 °C) is evaluated by measuring the weight loss and the burning rate. The results are presented in tables and diagrams and are statistically evaluated. This study investigated the effects of the thermal treatment of Merbau and Meranti wood on selected burning characteristics. The results obtained from raw (untreated) wood test specimens were compared to results obtained from the test specimens subjected to thermal treatment at 160 °C, 180 °C and 210 °C. The monitored characteristics were weight loss and the burn rate. The results showed that the thermal treatment of Merbau and Meranti wood significantly increased its flammability and accelerated its combustion. In addition, its burn rate was higher than in untreated wood, reflecting that it is necessary to add fire retardants to thermally treated Merbau and Meranti wood.

Keywords: *tropical woody plants, thermal modification, fire-resistant coating, weight loss, burning rate*

1. Introduction

Wood is used in many areas, e.g. as a construction and cladding material. It has the good weight-to-load capacity ratio and therefore it is possible to carry out wooden constructions in different areas. The material is used in exteriors, as well as interiors, of wooden buildings. The main disadvantage of wood is its ability to catch fire and burn, so lots of attention has been given to this issue for many years. There is the possibility to modify wood to increase the fire performance as well as other technical proprieties [1], [2].

The interest in thermally modified wood has significantly increased lately. This interest has arisen due to reduced production of wood as durable material, increased interest in durable construction material and legislative changes, which restrict the use of toxic substances. The large commercial importance is shown, as currently thermal wood is produced by five different modifications in Finland (Termowood), in the Netherlands (Plato Wood), in Germany (OHT - Oil Heat Treatment Wood) and two methods in France (Bois Perdure and Rectification). The process temperatures range between 160 and 260 °C and the differences between various modifications are represented by using the gas environment (nitrogen, steam), oils, different humidity levels and so on. Wood treated in such a way has better properties when used in exteriors, as well as interiors, e.g. dimensional stability, durability, color change and so on [3], [4].

The impact of thermal modification on anatomical, mechanical, physical, biological and chemical properties of wood has been the subject of many studies. In the scientific literature, however, no knowledge about fire characteristics of this thermal treated material is available. Fire characteristics are of main importance within wooden constructions. Even though there are studies dealing with thermally modified wood and its combustion [5], [6] the information on the reaction to fire performance for the modifications of thermally modified wood and the impact of these modifications on its properties is missing.

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The objective of this article is to assess properties of thermally modified wood, which characterize its ability to achieve flameless burning. A standard method is applied simulating real fires.

2. Thermal modification

In special furnaces, thermal modifications of wood are conducted using water, steam and high temperatures. The thermal modification device (special furnace) must be made of stainless steel and equipped with non-standardized fans and coolers. Biofuel, fuel oil, gas or electric heater are used as a propulsion agent. The whole process is conducted in three phases as described below in more details [7], [8].

2.1 Drying

Drying, i.e. the high-temperature drying, is the most time consuming phase of the process. During this stage, the moisture content of wood decreases almost to zero. Time of drying therefore depends on the initial moisture content of wood, specifications of the given type of wood and its thickness. Drying at high temperatures brings about greater elasticity and thus better resistance to deformations [1].

2.2 Heat treatment

This phase of thermal modification of wood begins immediately after drying. The heat treatment is carried out in an enclosed chamber at temperatures ranging from 185 to 215 °C. During the process, are used both steam-serving as the so-called protecting steam - and the protective gas preventing the wood from igniting and burning, which, however, influences the chemical changes inside the wood. The whole process takes up 2 to 3 hours [7].

2.3 Conditioning

The last phase of thermal wood treatment consists of cooling. During this stage, it is important to bear in mind that great differences in temperatures between wood and the outside environment may cause cracking. For its final use, wood must be re-damped to the appropriate level, since the final moisture content of wood has a significant impact on its operating characteristics. Once the phase has been completed, the modified wood should have a moisture content of approximately 5 to 7%. The whole process takes 5 to 15 hours [7], [9].

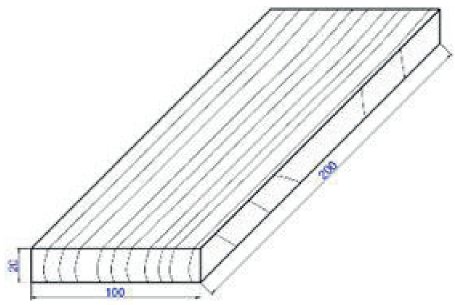

Figure 1 *Size of test samples (mm) to verify thermal modification for ignition and burning of this type of modified wood*

3. Experiment

3.1 Test samples of tropical woody plants

The test samples were made and modified in a thermal chamber (S400/03, LAC Ltd., Rajhrad, Czech Republic). Three final temperatures, 160, 180, and 210 °C, were chosen for the wood modification. The thermal modification used the ThermoWood principle developed by VTT (Finland), which takes place in a protective atmosphere (dispersed water in the air, to prevent overheating and burning), on the two tropical woody plants - Meranti and Merbau. Dimensions of samples were 200x100x20 mm (Figure 1) and they did not have any anatomical or production defects.

Five samples, made from both types of tropical woody plants, have been tested for each of the 4 temperatures of thermal modification, i.e. 20, 160, 180 and 210 °C.

The Meranti is a woody plant growing in Malaysia, Indonesia, Thailand and the Philippines. It has very hard wood with high resistance against pests, molds and weather conditions. The wood is of dark/light red color or of yellowish to white color and is very popular with buyers. Lighter wood is, however, more prone to breakage than the darker one [3], [10].

The Merbau is a type of woody plant growing in South East Asia, Indonesia, Vietnam, Thailand, Malaysia and the Philippines. At present, it is a very popular type of woody plant thanks to its hardness, firmness and brown coloring with golden stripes. In addition, it is characterized by the high durability and resistance against termites. From the point of view of its structure, it falls into the category of scattered porous woody plants [3], [10].

The structure of the given woody plants is shown in Figure 2.

3.2 Test apparatus

From the large number of test methods available a test method simulating conditions of real fire has been selected. Naked flame - of a constant value in an open space, not in an

***Figure 2** Structure of Meranti (on the left) and Merbau (on the right) [3]*

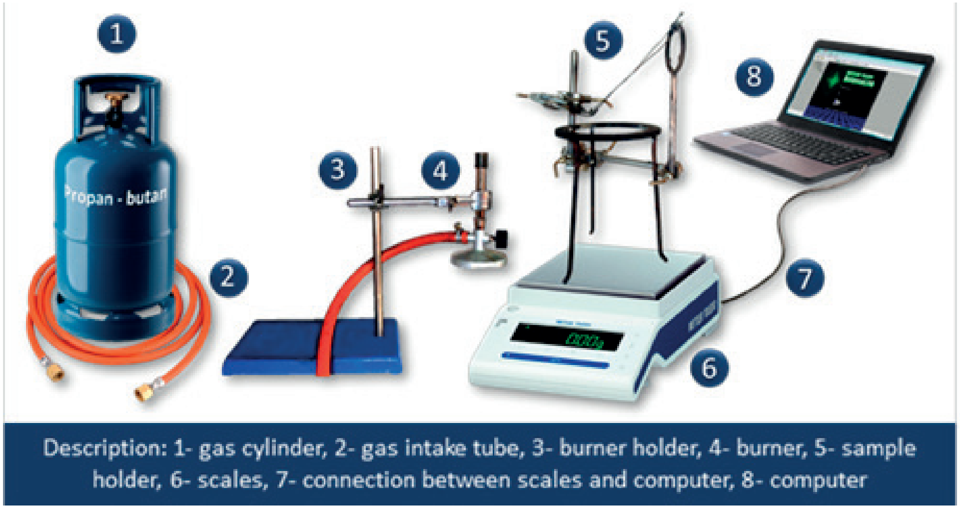

***Figure 3** Test apparatus scheme [12]*

enclosed laboratory environment - serves as a heat source. The method in question is a non-standardized EU method; however, it is traditionally used in material evaluations and their fire-retarding modifications [2], [11].

Each test sample was directly exposed to the flame of propane gas burner for 10 minutes. The test sample was placed at the angle of 45° to the horizontal plane. The flame had a length of 100 mm and the center of sample was 90 mm from the mouth of the burner. Basic measurements were carried out for 10 minutes, auxiliary measurements took additional 5 minutes (without using any heat source).

The apparatus, which was relatively simple, consisted of USBEC 1011/1 propane gas burner, which served as a regulated flame source (DIN-DVGW reg. Pan NG-2211AN0133) 1.7kW. Weight was measured using the Mettler Toledo scales with an accuracy of 0.01 g (MS 1602S / MO1, Mettler Toledo, Geneva, Switzerland). Weight changes of samples (evaluation criteria) have been recorded and the test has been carried out using the BalanceLink 4.2.0.1 (Mettler Toledo, Switzerland). During the experiment, weight change interval was set to 10 seconds. Diagnostic laboratory equipment is depicted in Figure 3.

3.3. Processing of numerical values

The main assessment criterion - weight loss of test samples - was calculated according to equation:

$$\delta_{mr}(\tau) = \frac{m(\tau) - m(\tau + \Delta\tau)}{m(\tau)} \cdot 100 \tag{1}$$

where:
$\delta_{mr}(\tau)$ – relative weight loss at time (τ) [%],
$m(\tau)$ – weight of the sample at time (τ) [g],
$m(\tau + \Delta\tau)$ – weight of the sample at time $(\tau + \Delta\tau)$ [g] [4].

The relative weight loss value was used to calculatethe relative burning rate:

$$v_r = \frac{\delta_m}{\Delta\tau} \tag{2}$$

where:
v_r – relative burning rate [%/s^1],
δ_m – relative weight loss in time (τ) [%],
$\Delta\tau$ – time interval recording weights [s] [4].

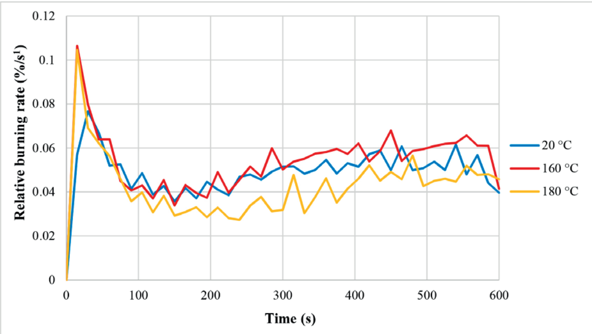

Figure 4 Relative burning rate of the Meranti samples

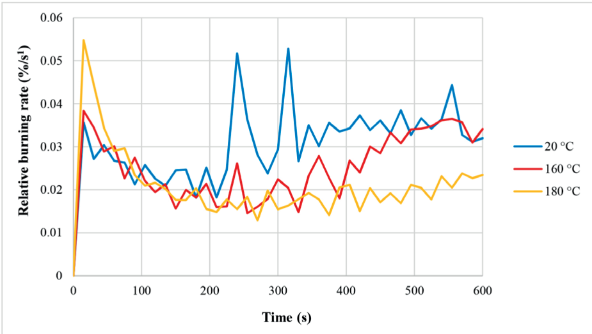

Figure 6 Relative burning rate of the Merbau samples

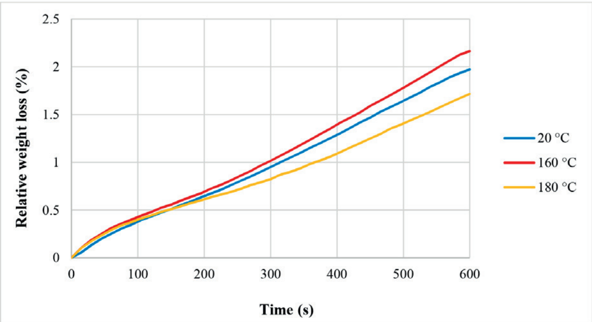

Figure 5 Relative weight losses of the Meranti samples

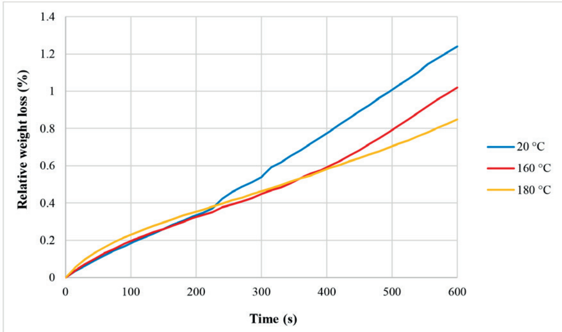

Figure 7 Relative weight losses of the Merbau samples

The impact of different densities of test samples on the results of the evaluation criteria was also observed. Density is calculated according to the following relation:

$$\rho = \frac{m}{V} \tag{3}$$

where:
ρ - sample density [kg/m^3],
m - total weight of the sample [kg],
V - total volume of the sample [m^3] [4].

4. The results

This section includes graphically processed results of the evaluation criteria. The first part presents average values of relative burning rate and relative weight loss of Meranti samples (Figure 4 and Figure 5, respectively) and the second one shows the summary of the same values in the same order for Merbau samples (Figure 6 and Figure 7, respectively).

Figure 4 shows rapid increase in burning rate as a result of flame exposure onto the test sample for all three thermal modifications of Meranti samples. After approximately 20 seconds, the burning rate slowed down, but a slight acceleration occurred from approximately 180 second. Samples at 20 °C and 160 °C were burning at an average speed of 0.05 %/s^1 and the sample at 180 °C by one hundredth of a second slower.

Weight losses of the samples are directly related to the above-mentioned changes in density. Figure 3 shows a detailed illustration of the process for some of the samples calculated based on relation (1).

The more significant course of relative burning rate was recorded for the Merbau samples, which is also demonstrated in the charts in Figure 6.

With both relative weight loss and relative burning rates, the rapid growth in burning rate can be observed within the very first seconds. Slowdown of burning rate occurs after approximately 20 seconds. Re-acceleration, however, differed for each sample. The sample at 180 °C was burning at an average speed of 0.02 %/s but the process was similar as with Meranti samples. Sample at 160 °C showed some slight extremes from approximately 220 second up to approximately 380 second and burning rate subsequently rapidly accelerated. The biggest variations have been recorded for the sample at 20 °C. The two peak values have been recorded and the subsequent burning proceeded more rapidly than with the other samples of different heat treatment but rather evenly.

Since the weight losses are directly related to changes in density, Figure 5 shows significant dominance samples at 20 °C over the other samples, making a difference between the flammability level of Merbau and Meranti samples. The results show that the Merbau samples resist the effect of flame a little more than the Meranti samples, since of those samples shows average values ranging from 0.02 to 0.03 %/s, whereas it is 0.04 to 0.05 %/s for the Merbau samples.

However, when comparing relative weight losses of the woody plants (separately), one can see that the Merbau samples at 20 °C surpass, on average, the weight losses of the samples at 160 °C. With the same criteria for the Meranti samples, the result is quite the opposite. Variations, that are represented by the maximum deviations in Figure 4 with the sample at 20 °C, are likely to be caused by the so-called random errors.

5. Conclusions

Thermally modified Meranti and Merbau woods have greater weight losses in open flame burning than woods that were untreated. Thermally modified Meranti and Merbau woods have a greater ability to ignite and burn more intensely than untreated Meranti and Merbau woods. It is clear from those results that thermally treated Meranti and Merbau woods, at all temperatures, have higher burn rates than untreated Meranti and Merbau woods. The Meranti and Merbau woods begin to burn after 10 s of exposure to the flame, and from 100 s to 130 s flares up significantly, resulting in a high burn rate. The highest burn rates occur within the first 200 s. The burn rate is the highest in the Meranti and Merbau woods that were thermally modified at 160 °C. The thermally treated Meranti and Merbau woods showed higher burn rates throughout the test, even after they exceeded the highest burn rate of untreated samples. For this evaluation criterion, one can also determine the causes of these phenomena, as was for the weight losses. The results show that thermally treated Meranti and Merbau woods greatly increase their ability to ignite and combust, and increase their burning intensity. This was also confirmed by the selected evaluation criteria. The authors recommend the addition of fire retardants to the thermally modified woods, which is also the objective of future experiments.

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