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EFFECT OF THERMAL AND RETARDING TREATMENT ON FLAMMABILITY RATE OF TROPICAL TREE SPECIES

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ABSTRACT

Wood is integral to the construction industry despite the fact that it is a highly flammable material. Due to thermal stress, it is subject to the process of pyrolysis. However, not every type of wood burns the same. This dissimilarity is caused by the changes in its internal structure. Flammability rate of tree species can be modified by means of thermal modification, i.e. change in its internal structure or by using coating compositions which form a fire-protecting layer on its surface.

The paper comprises a testing and an evaluation of iroko wood which is predominantly used as floor covering and cladding material for building structures. The authors focus on determining the connection between the structure of this exotic tree type and the eventual thermal degradation (burning course, significant changes, amount of material burnt, etc.) of the samples. Small size samples were used during laboratory measurements. Their width and thickness were approximately the same as for commonly used cladding boards. The data obtained in the laboratory have been processed, transformed into evaluation criteria and connected with theoretical knowledge, creating an overview of its eventual flammability.

Laboratory test results prove low flammability rate of test samples. Mass loss was an important criterion. Thermal treatment, which changes the internal structure and thus improves its properties (T group; test samples), had no significant effect on the eventual flammability. On the other hand, the flammability rate of samples was better when using a fire retardant (R and TR group; test samples), because the retardant lowers the flammability by more than half.

KEYWORDS: Tropical tree species, thermal treatment, fire retardant, internal structure, laboratory testing, flammability rate.

INTRODUCTION

Innovations and the application of tropical tree species as interior and exterior facing materials are on the increase in the building industry. Besides their more distinctive coloring, compared to domestic tree species, they have more advantageous physical and mechanical properties. This fact results from different internal structure and the proportion of substances that are found in different parts of the wood. This is caused by the environment the trees grow in. The environment is characterized by a relatively constant temperature (around 25°C) and high humidity rate. Their wood is solid and hard (Rowell et al. 2005).

Physical and mechanical properties of tropical tree species are significantly affected by its structure. The cell wall of such wood is, in large part, made up of cellulose and hemicelluloses and hydroxyl groups make the cell wall in these parts hygroscopic, i.e. absorbent. This property, however, is reduced by the amount of lignin the wood contains, representing the hydrophobic binder and its amount is quite significant within tropical trees (Jiangtao 2015). This means that these cell walls have greater affinity to water, but the ability of the walls to absorb water is partly limited by the presence of lignin which thus reduces its flammability rate (Glass 2010).

By adjusting the internal structure, more acceptable properties of wooden materials can be achieved. Fire retardant is a simple and commonly used fire protective agent for wooden materials. It is usually a liquid synthetic agent which should create a protective layer on the surface of the material. The coating is supposed to either insulate the material completely from any flames or to keep the material intact for a certain period of time since the coating can withstand fire for some time (Gutiérrez 2017).

Since it is possible to influence the flammability rate of wood, the idea to compare the flammability of tropical tree species, depending on the level of their treatment, originated.

A substantial part of this article therefore lies in evaluating the flammability rate of the selected tropical tree species – untreated ones as well as tree species with a structural or surface treatment (thermal modification, fire retardant coating). The conclusions are based on the data obtained from the laboratory measurements of small size test samples.

MATERIAL AND METHODS

Laboratory tests were carried out using small size samples made from Iroko wood/African teak (Fig. 1). This type of wood has medium to coarse texture and open pores.

Fig. 1: Surface of iroko wood (The wood 2018).

The wood in question is very stable thanks to its high content of non-structural features and is characterized by its high durability. It is rot and termite resistant (Wiedenhoeft 2010). After being felled, the wood has yellow (lemon) color but it oxidizes quickly when exposed to air and its surface gradually turns from tawny to dark brown in color. Thanks to its durability, Iroko wood is a more affordable alternative of teak wood (Olorunnisola 2018).

Test samples were made using tangential cut from the hard wood layer. 40 samples were tested in a fire-chemical laboratory. Each treated as well as untreated samples had the dimensions of 200 x 100 x 20 mm (Fig. 2). The test specimens were as follows:

a) 10 untreated samples (no thermal adjustment or fire-retardant treatment),
b) 10 thermally treated samples at 180°C, no fire-retardant treatment,
c) 10 thermally untreated samples coated with a fire retardant,
d) 10 thermally treated samples at 180°C and coated with a fire retardant.

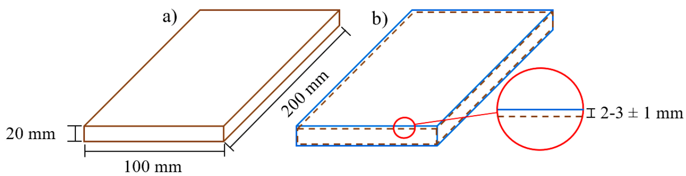

Fig. 2: a) Sample dimensions b) Coating thickness.

All samples were air-conditioned under specific conditions (relative moisture content of 65%±3%, temperature of 20°C±2°C) to achieve an equilibrium moisture content of 12%. The thermal treatment in question is a heat treatment process using water, water vapor and high temperatures in S400/03 thermal chamber (LAC Ltd., Rajhrad, Czech Republic) according to ThermoWood® principle originally developed by VTT (Finland). A device used for thermal adjustment is solely made of stainless steel and equipped with enough fans and coolers. Bio-fuel, fuel oil, gas (even electrical heaters sometimes) are used as the propulsion power of the system. The whole process is divided into three stages (Finnish 2003):

1. high-temperature drying - the most time-consuming stage of the whole heat treatment process. During this stage, the moisture content of wood is reduced almost to 0. By drying tree species at high temperatures, greater elasticity and thus better resistance to deformation can be obtained (Finnish 2003). The process took 13.1 hours.
2. heat treatment - started immediately after drying. It was conducted in an enclosed chamber at the temperature ranging from 180 to 215°C. During the process, steam and protective gas preventing the wood from burning are used. The latter, however, induces some chemical changes in wood (Finnish 2003). The process took 3 hours.
3. cooling - at this stage it is important to bear in mind that the significant temperature disproportion between the wood and the outside environment may result in the formation of cracks. However, the wood must be re-moistened to the appropriate level for the final use since the final moisture content of wood has a significant impact on its operating characteristics (Finnish 2003). Once the phase is over, modified wood contains approximately 5 - 7 % of moisture. The process took 6.2 hours.

The average density of the treated samples was 608.97 kg·m^{-3} ± 69.65 kg·m^{-3} at the moisture of 6.6 %.

Retarding treatment means coating the samples with synthetic flame retardant Flamgard which is one of the most common protective coatings for wooden constructions. It is a single-component foam-generating water dilatable coating. It contains a coke-forming component, a component of phosphoric acid, various binders, fillers, additives and auxiliary substances. The coating creates a white dull film that prevents fire from spreading. According to ČSN 13501-1+A1, it belongs to the group of the substances with B-s1, d0 class reaction to fire (Security 2016).

According to (Drysdale 2011), there are two aspects affecting the spread rate of flame. Firstly, it is the angle the material forms because the lift of combustion products contributes to better development of flame and, secondly, the combustion gases preheat, to a great extent, the unburned surface, creating more natural environment for burning. Faster burning will therefore be happening from the inside (bottom part) (Fig. 3) rather than from the outside (upper side).

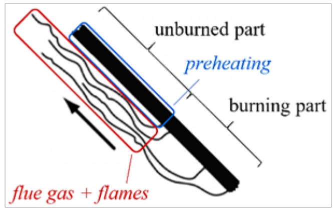

Fig. 3: Fire dynamics (Drysdale 2011).

On the basis of physical principles of fire spread along the surface of a flammable material, test equipment, whose design is based on STN 73 0862 directive - appendix b, is used. Digital scales, a stand (enabling to fix the samples at the desired angle), a holder for Bunsen burner, a sample holder and a (propane-butane) gas bomb have been used (Fig. 4).

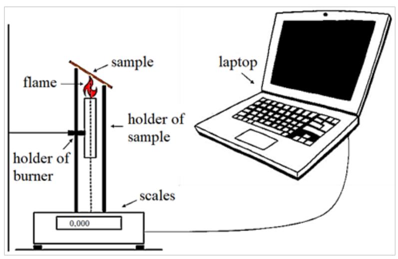

Fig. 4: Scheme of the test equipment.

Samples have been fitted to the holder at the angle of 45°. Heat source was applied from below and into the center. Each sample has been tested in an identical way for 600 seconds. During this time, mass loss, caused by continuous stress when the sample was exposed to a flame with the burner output of 3.3 kW, is being monitored and recorded every 15 seconds. Approximately 50.4 $g{\cdot}s^{-1} \pm 4.2\ g{\cdot}s^{-1}$ of gas was used per sample.

Primary output measurements are represented by the figures showing the change in mass of the test samples recorded using BalancLink software and then copied to MS Excel.

Relative mass loss and relative burning rate were calculated using the appropriate mathematical calculations.

RESULTS AND DISCUSSION

The chapter includes photos of the sample during and after the test and mathematically processed data necessary to summarize the eventual flammability rate of tropical tree species.

Some visual and acoustic side effects occurred (cracks, leaks, bubbling, sparking) during the test depending on the given test group which was exposed to thermal stress. On the basis of these changes, the tested groups of specimens can be divided into two groups. The greatest differences manifested themselves due to fire retardant coating. When exposed to fire, the surface of the sample (coating) is cracking first. Untreated samples show much less significant visual or acoustic changes.

Fig. 5 demonstrates the course of the experiment. The sample and the burner can be seen in the picture on the left. The photo on the right shows thermal degradation of a test specimen.

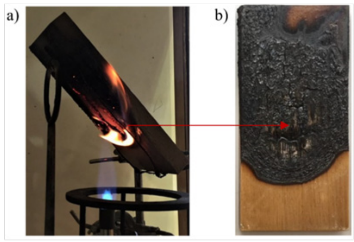

Fig. 5: a) Sample during the test b) The sample after the test.

The mean of relative burning rate shown in the chart in Fig. 6 was the main assessment criterion during burning. Test sample groups were labeled as follows:

N - untreated samples,

T - thermally treated samples (180°C),

R - thermally treated samples with no fire retarding treatment,

TR - thermally treated samples (180°C) coated with fire retardant.

The chart below shows that the four groups of samples were pared down to two groups based on their course of burning. Burning rate of N and T samples were ranging at approximately 0.194 %.s^{-1}. Average relative burning rate of R and TR samples was only 0.083 %.s^{-1}. The variance between the groups is thus significant.

In every single case, the sample started to burn down rapidly at the very beginning - between approximately 20th and 140th second. The burning stabilizes after a while.

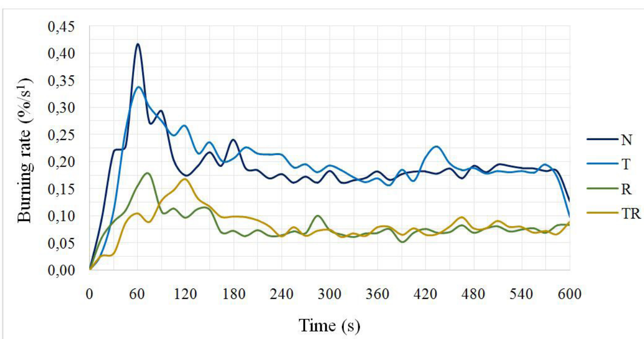

Fig. 6: Average relative burning rate of test samples.

Mass loss (%) was monitored during the test (Fig. 7).

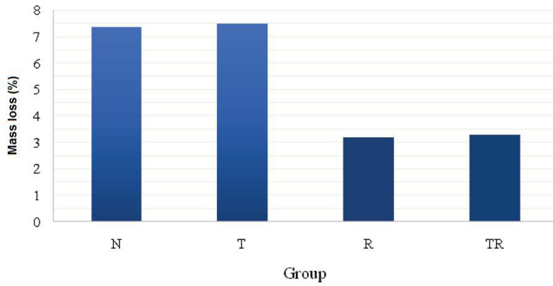

Fig. 7: Average mass loss of test samples.

The picture shows a rapid decrease in mass of N and T samples. In comparison with the other two, there is an average variance of 4.19%. This is caused by thicker charred layer, i.e. pyrolysis of lower layers.

ANOVA method was used to determine the significance of variances between the means of these sample groups. Necessary hypotheses were laid down: H_0 = fire retardant reduces the flammability rate of wooden test samples and H_1 = fire retardant does not reduce the flammability rate of wooden test samples.

First of all, normality tests had been carried out followed by a comparison of the tested groups. Normality test results can be seen in Tab. 1.

Tab. 1: Test of homogeneity of variances.

	Levene Statistic	df1	df2	Sig.
T	1.36	31	9	.325
R	2.41	31	9	.082
TR	3.14	31	9	.037

Tab. 2 contains ANOVA test results which represent the most important data group. It tells us whether or not the groups have significant statistical variances among themselves.

Tab. 2: Outputs of ANOVA.

		Sum of squares	*df*	*Mean square*	*F*	*Sig.*
T	*Between Groups*	.14	31	.00	13.62	.000
	Within Groups	.00	9	.00		
	Total	.14	40			
R	*Between Groups*	.03	31	.00	4.32	.013
	Within Groups	.00	9	.00		
	Total	.03	40			
TR	*Between Groups*	.03	31	.00	4.25	.014
	Within Groups	.00	9	.00		
	Total	.04	40			

From a statistical point of view, R and TR sample groups differ significantly from N group: F_R = 4.32 a p > 0,001, width of the spread of r = 1 a F_{TR} = 4.25 and p > 0.001, width of the spread of r = 0.87. Width of the spread has been calculated as a square root of "Between Groups" and "Total" and in these two cases it is an indicator of high variance. T group differs from N group minimally since $p < 0.001$. Based on these results, H_0 hypothesis is true.

Based on the tests, exotic wood Iroko and Flamgard fire retardant seem to have reliable fire properties of organic materials. However, we cannot be sure whether thermal modification improved the properties of the wood since wood treated in special furnaces at higher temperatures may change its structure and improve its properties to the extent that the results will vary significantly. This claim can be proved to be true by comparing the results of our research with the ones described (Osvald 2017). Even though the process of thermal treatment was the same, the results differ. For thermally modified Iroko samples, a certain disruption of thermally modified samples was recorded, but not as substantial as for the spruce wood samples using the given outputs. This fact can be caused by the combination of two factors: different internal structure of the tropical tree species and the effect of thermal modification on the properties of tropical wood, i.e. disruption of its internal structure was of a lesser extent than for the domestic tree species, causing a slight difference in flammability rate results.

In general, untreated natural wood products have flame indices (*FSI*) of 90-160. For a few tree species, the index is below 75 (redwood) and others have values above 170 (yellow- poplar). While untreated wood commonly has an FSI of 90-160, wood treated with commercial fire retardant has an *FSI* < 25. These data are taken (Sweet 1993). The author also points out that fire retardant treatment of wood can substantially reduce heat release rate HRR.

Candelier et al. (2013) and other scientists also studied mass loss along with heat treatment. They concluded that thermal degradation kinetic of wood depends on wood species and process conditions such as drying step, heating medium and treatment intensity. Brenden (1975) found out that treating Douglas-fir plywood with inorganic salt fire retardants decreased smoke yield under nonflaming conditions. It was described in his scientific work, when the author came to conclusion that smoke yield from the wood treated with a retardant is lower than for untreated material. Further it researched how an acid-catalyzed reaction in the fire retardant reduce the flammability of wood by that decreases the temperature at which wood begins to decompose and increases the residual char weight. It was found that the presence of acids in the wood can significantly reduce strength (LeVan 1990). It is necessary to note that density will have an impact on the evaluation criteria (changes in temperature, influence of heat flow). This fact was also observed on the home-grown timber in an article, who's the main objective was the experiment focus on testing reaction of fire on two different types of surfaces (Gašpercová 2017).

CONCLUSIONS

The results of the laboratory test using small size test specimens prove low flammability rate of iroko wood since mass loss reached low values for each test group (N, T, R and TR).

The interesting fact is that thermal treatment, which changes the internal structure and thus improves its properties, had no significant effect on the eventual flammability rate, whereas surface modification using the flame retardant did. The results thus show that the material treated with Flamgard fire retardant (layer of 2-3 mm) lowers the flammability rate of iroko wood by more than half, regardless of the adjustments induced by thermal modification. Based on the information about Flamgard, we can sum up that burning rate is lowered and influenced mainly by its foaming ingredients which, in contact with fire, prevent the flames from spreading. This phenomenon may also occur if Flamgard is applied onto a different type of tree, but it can respond in an entirely different way than iroko wood. Such research will be the groundwork for the next article. We verified the conclusions using ANOVA statistical method.

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REFERENCES

1. Brenden, J.J., 1975: How nine inorganic salts affected smoke yield from Douglas-fir plywood. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, 12 pp.
2. Candelier, K., Treu, A., Dibdiakova, J., Larnøy, E., Petrissans, A., Dumarçay, S., Pétrissans, M., Gérardin, P. 2013: Utilization of TG-DSC to study thermal stability of beech and silver fir. No. IRG/WP 13–40628. The International Research Group on Wood Preservation.
3. Drysdale, D., 2011: An introduction to fire dynamics. 3rd ed. Chichester, West Sussex, Wiley. 574 pp.
4. Finnish thermowood association 2003: ThermoWood Handbook. Helsinki: c/o Wood Focus Oy. 66 pp.
5. Gašpercová, S., Osvaldová, L., 2017: Influence of surface treatment of wood to the flame length and weight loss under load single-flame source. Key Engineering Materials, 755: 353-359.
6. Glass, S. V., Zelinka, S. L., 2010: Moisture relations and physical properties of wood. Wood handbook: wood as an engineering material: chapter 4. Centennial ed. General technical report FPL; GTR-190. Madison, WI: U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory, Pp 4.1-4.19.
7. Gutieres, T.J., Alvarez, V.A., 2017: Cellulosic materials as natural fillers in starch containing matrix-based films: a review. Polymer Bulletin 74(6): 2401-2430.
8. Jiangtao, S., Li, J., 2015: Metabolic profiles in wood forming tissue during tension wood formation. Wood Research 60(4): 531-542.
9. Levan, S.L., Winandy, J.E .,1990: Effects of fire retardant treatments on wood strength: A review. Wood and Fiber Science 22(1): 113-131.
10. Olorunnisola, A. O., 2018: Anatomy and physical properties of tropical woods. In: Design of structural elements with tropical hardwoods. Springer International Publishing. Pp 7-29.
11. Osvald, A., Gaff, M., 2017: Effect of thermal modification on flameless combustion of spruce wood. Wood Research 62(4): 565-574.
12. Rowell, R. M. et al., 2013: Cell wall chemistry. In: Rowell, Roger. ed. Handbook of wood chemistry and wood composites, Second edition. Boca Raton, FL: CRC Press, Chapter 3, Pp 33-72.
13. Security data card, 2016: Flamgard Transparent. Stachema, 9 p. Available on: https://www.stachema.sk/files/files/FLAMGARD.

14. STN 73 0862: Determination of flammability degree of building materials.
15. Sweet, M. S., 1993: Fire performance of wood: test methods and fire-retardant treatments. In: Recent advances in flame retardancy of polymeric materials. Proceedings of the 4th annual BCC conference on flame retardancy, 1993. May 18–20. Stamford, CT: Business Communications, Pp 36-43.
16. The wood database [online]. Iroko [cit. 2018-09-20]. Available on: https://www.wood-database.com/iroko/.
17. Wiedenhoeft, A., 2010: Structure and function of wood. In: Wood handbook: wood as an engineering material. Madison, WI: Forest products, Pp 3.1-3.18.

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