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THE INFLUENCE OF DENSITY OF TEST SPECIMENS ON THE QUALITY ASSESSMENT OF RETARDING EFFECTS OF FIRE RETARDANTS

Linda Makovická Osvaldová, Stanislava Gašpercová
Patrik Mitrenga, Anton Osvald
University of Žilina in Žilina, Faculty of Safety Engineering
Žilina, Slovak Republic

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ABSTRACT

Test methods evaluating wood flame retardant efficiency are comprised of a parameter which is often considered to be an evaluation criterion and its calculation includes the weight of the test specimen or takes into account the change of its weight during the test. In this case, the overall result may be affected not only by the weight of the test specimens, but also by their density. Our aim is to observe the influence of density while evaluating the efficiency of wood flame retardants.

KEYWORDS: Wood combustion, wood flame retardation, tests of fire retardant efficiency.

INTRODUCTION

Archimedes is considered to be the discoverer of density. In physics, a solid is characterized by a certain volume V, in which some mass m is spread either continuously or not. Mathematical and physical thinking allow us to introduce the concept of density of a solid in the given point as a limit (Danihelová 2010) (Eq.1) and at the same time it can be defined through the total weight of the solid *m* by an integral (Danihelová 2010) (Eq. 2).

$$\rho(\mathrm{x, y, z}) = lim_{\Delta V \to 0} \frac{\Delta m}{\Delta V} \quad (1)$$

$$m = \int \rho(x, y, z) \Delta V \quad (2)$$

where in the Eqs. 1 and 2: m - weight (kg),
V - volume (m^3),
x, y, z – coordinates,
ρ - density ($kg.m^{-3}$).

The given mathematical notations apply to all kinds of materials. Density is considered to be the most important wood characteristic. Wood is a natural heterogeneous material, considering its chemical composition and other proprieties, so other terms considering its density have been introduced. Wood density also depends on the chemical composition of wood, its anatomical structure, its location within the tree trunk, its geographical location, climatic and growing conditions as well as on the type of the tree. Individual wood samples are divided into several density groups: wood of low density ($\rho12 < 540$ kg.m^{-3}), wood of medium density ($\rho12$ = 540-750 kg.m^{-3}) and wood of high density ($\rho12 > 750$ kg.m^{-3}). In the previous line, index 12 is stated for the density. It means that wood is a material which contains water. The term - wood density for various moisture contents - has been introduced: dry wood density (w = 0 %), wood density at a humidity of 12 %, wet wood density (w > 0 %) (Trebula and Klement 2005, Požgaj et al. 1997). Terms like reduced density, conventional density, etc. have been introduced as well. Various authors deal with wood density of different tree species (Carrillo at al. 2015, Zeidler and Šedivka 2015, Tsuomis 1991, Martinka and Chrebet 2014a).

This physical property affects all technological processes, starting with the purchase of wood, its drying (Trebula and Klement 2005), production of large-sized materials and composites (Barbu et al. 2014) and other wood products (Martinka at al. 2013, Martinka and Chrebet 2014a, Martinka at al. 2014b, c), its impregnation (Veľková et al. 2007) as well as wood waste. It influences the mechanical properties too (Kuklík and Kuklíková 2010, Osvald 1984, 1995), therefore it has a direct impact on the production of components and parts for wooden constructions.

Wood density interferes in other areas connected with the evaluation of wood and its properties (Zachar and Marková 2009, Carrillo 2015, Osvald 1997). It also applies to the evaluation of fire safety properties and retardant adjustments. No matter what assessment methodology we use (either the standard test methods, or conical calorimeter) if the weight change or the change in thermal properties are used as the evaluation criterion, density may affect the results of the test. In almost all methodical instructions, the parameters such as wood moisture content, the climate, the thickness or quality of the wood are provided but the density (at least at limit values) is missing. This article aims to find out the influence of density of spruce wood specimens on the final results of the experiments.

MATERIAL AND METHODS

Material

Norway spruce (*Picea abies* (L) Karst.) is the second most widespread type of wood in Slovakia and the most important one from the economical point of view. Spruce wood is yellowish to yellow-brown, glossy, with colourless heartwood, very bright, light, soft, elastic, splits easily and is easy to stain but more difficult to impregnate (Balabán 1955). It is characterized by a symmetrical and narrow annual rings (1 to 4 mm) with a share of summer wood in an annual circle ranging from 5 to 20 % (Wagenführ 2007). The wood was used to manufacture test specimens which were sorted out according to their density. 60 pieces out of 450 samples have been divided into two density groups (see Tab. 1) low density LD, and high density HD.

Tab. 1: Density in the given categories.

Density	LD	HD
Minimum density	369.84	543.12
Average density	375.42	554.07
Highest density	385.44	577.64

The metodology

From both density categories (45 test specimens in each), 15 samples were selected for testing in their unrefined form (no retardant being used, low density LD0, high density HD0), treated with a single layer of fire retardant on both sides (low density LD1, high density HD1) and treated with a double layer of fire retardant on both sides (low density LD2, high density HD2).

Fire retardant

A random retardant has been chosen for the experiment. The selected retardant will not be characterised or specified in more details. The aim of the experiment was not to assess the retardant. The aim was to find out if the density of the test specimens has any impact on the overall result even when applying a retardant.

Thermal load

The principle of heat load has been selected from the traditional test method where the main assessment criterion is the weight loss. The test in question is represented by the test specimens of 200 x 100 x 10 mm (10 mm thick) exposed to flame of the gas burner. The centre of the specimen was exposed to the flame for 10 minutes, forming a 45° angle with the horizontal line. Perpendicular distance between the centre of the sample and the mouth of the burner was 90 mm, with the flame height of 100 mm.

Evaluation criteria

Weight loss

During the exposure to thermal radiator, the weight loss was being observed and recorded, on the basis of which the relative weight loss has been calculated (Eq. 3):

$$\delta_m(\tau) = \frac{\Delta m}{m(\tau)}.100 = \frac{m(\tau)-m(\tau+\Delta\tau)}{m(\tau)}.100 \qquad (\%) \tag{3}$$

where: $\delta_m(\tau)$ - relative weight loss in time (τ) (%),
$m(\tau)$ - sample weight in time (τ) (g),
$m(\tau+\Delta\tau)$- sample weight in time ($\tau + \Delta\tau$) (g),
Δm - the difference in weight (g).

Relative burning rate

Relative burning rate has been determined in accordance with the relations (4) (5):

$$v_r = \left|\frac{\partial \delta_m}{\partial \tau}\right| \qquad (\%/\text{s}) \tag{4}$$

or numerically

$$v_r = \frac{|\delta_m(\tau)-\delta_m(\tau+\Delta\tau)|}{\Delta\tau} \qquad (\%/\text{s}) \tag{5}$$

where: v_r - relative burning rate (%.s),
$\delta m(\tau)$- relative weight loss in time (τ) (%),
$m(\tau + \Delta\tau)$ relatíve weight loss in time(τ + Δτ) (%),
$\Delta\tau$ - time interval when the weights are being subtracted (s).

RESULTS AND DISCUSSION

The results are presented in forms of graphs. Figs. 1-3 represent the weight loss process, Fig. 1 for unrefined wood of low (LD0) and high (HD0) density, Fig. 2 for wood of low (LD1) and high (HD1) density treated with a single layer of fire retardant and Fig. 3 for wood of a low (LD2) and high (HD2) density treated with a double layer of fire retardant. Fig. 4 shows a bar chart with the highest values of weight loss for the individual variations of the experiment. Figs. 5-7 show the course of burning rate. Fig. 5 for unrefined wood of low (LD0) and high (HD0) density, Fig. 6 for wood of low (LD1) and high (HD1) density treated with a single layer of fire retardant and Fig. 7 for wood of low (LD2) and high (HD2) density treated with a double layer of fire retardant.

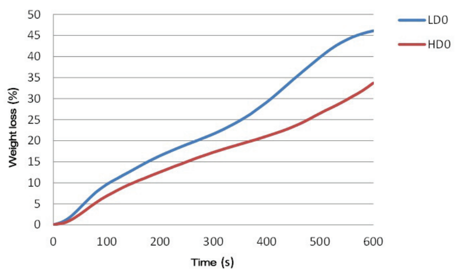

Fig. 1: Course of weight loss for unrefined wood of low (LD0) and high (HD0) density.

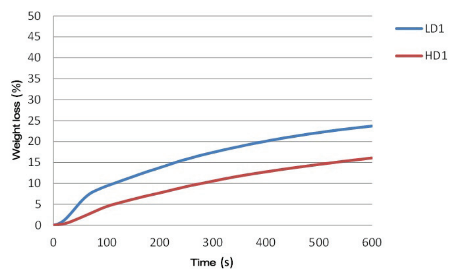

Fig. 2: Course of weight loss for wood of low (LD1) and high (HD1) density treated with a single layer of fire retardant.

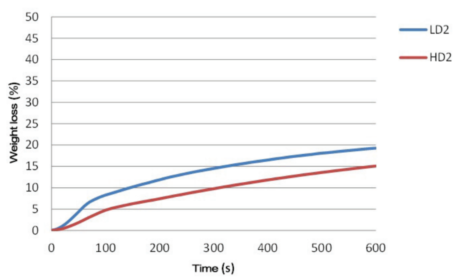

Fig. 3: Course of weight loss for wood of low (LD2) and high (HD2) density treated with a double layer of fire retardant.

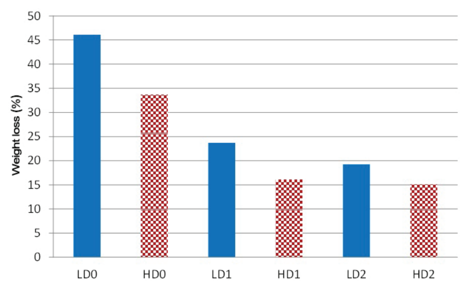

Fig. 4: The highest values in weight loss for the individual variations of the experiment.

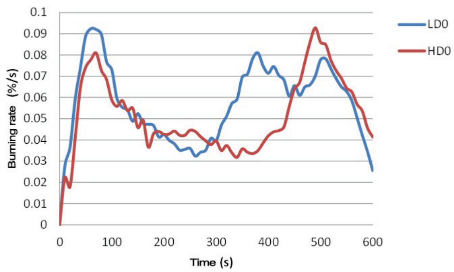

Fig. 5: Course of burning rate for unrefined wood of low (LD0) and high (HD0) density.

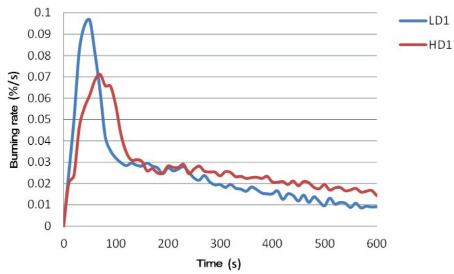

Fig. 6: Course of burning rate for wood of low (LD1) and high (HD1) density treated with a single layer of fire retardant.

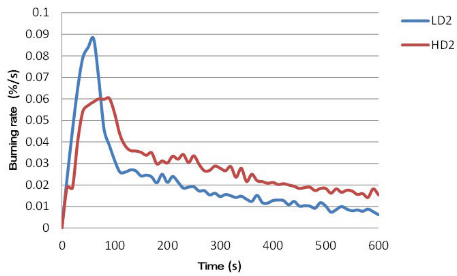

Fig. 7: Course of burning rate for wood of low (LD2) and high (HD2) density treated with a double layer of fire retardant.

All the above charts clearly show that density of test specimens has an influence on the overall results of the experiment i.e. the evaluation criterion of the test. With the unrefined samples, the influence of the density is clear. With the fire retardant treated samples of various density categories (see Tab. 1), the difference in the results averaged up to 12.4 % (low density-weight loss of 46.11 %, high density-weight loss of 33.71 %). The influence of the retardant was obvious. The weight losses were lower than with the samples which had not been treated with any fire retardant. With a single layer coating (low density, weight loss was 23.7 %, high density-weight loss of 16.08 %), the difference in density was 7.62 %. With a double layer coating (low density, weight loss of 19.27 %, high density, weight loss of 15.07 %), the difference in densities was 4.02 %. The shapes of the curves as well as the results of the experiment, considering the differences in weight loss between low and high density samples, confirm the influence of density on the result of the experiment. Although the differences shrink, it was possible to detect them.

This also applies to the second evaluation criterion-burning rate. With the unrefined samples, the burning rate peak is higher than at a higher density. This graph has an important explanatory value. With the unrefined samples (also confirmed by Martinka et al. 2014b, Mitterová and Zachar 2013, Draxlerová et al. 2014, Martinka et al. 2013, Xu et al. 2010) there is also a second burning rate peak. This applies in our case as well. Although the peak at a lower density is less than 0.0810 %/s, it has been recorded in 380.second of the experiment. At a high-density, the burning rate was 0.0928 %/s, (higher by 0.0118 %/s) however the value was achieved after 490 seconds of the experiment, i.e. 110 seconds later. This time readout is very important from the point of view of fire protection as -when assessing materials- the later the ignition occurs the better. Thus, with this evaluation criterion, we consider the influence of density to be apparent. In case of a single layer retardant coating, maximum burning rate of 0.0966 %/s in 50 seconds has been achieved with low-density samples, 0.0712 %/s in 70 seconds of the experiment with high-density samples. In case of a double layer retardant coating, maximum burning rate of 0.0866 %/s in 60 seconds of the experiment has been achieved with low-density samples, 0.0602 %/s in 90 seconds with high-density samples. With this evaluation criterion, the influence of the density has been detected in both - the burning rate as well as in the time when this value has been reached. The influence of retardant adjustment is obvious, however, it did not overwhelm the influence of the density of test specimens.

CONCLUSIONS

We can conclude that density of the wood specimens has a direct impact on the results of fire retardant efficiency. In this experiment, we only monitored the evaluation criteria which are related to weight, respectively, to its change during the evaluation of wood flame retardants. The experiment confirmed that the more retardant is being applied, (respectively the higher the quality of the retardant is) the lower the influence of density is, but it will never be negligible. Moreover, if a quality selection of the test specimens (considering the density before the application of the coating respectively before the experiment) is not carried out, it can lead to a great variability of the results obtained within the test group. The auxiliary statistical criteria may affect the overall evaluation of the given retardant. It is necessary to note that density will also have an impact on the evaluation criteria which aim to track the changes in temperature, respectively the influence of heat flow.

REFERENCES

1. Balabán, K., 1955: Wood science. 1. Part of the anatomy of wood. Prague: SZN Prague, 220 pp (in Czech).
2. Barbu, M.C., Réh, R., Irle, M., 2014: Wood based composites. Source title: Research Developments in Wood Engineering and Technology, 45 pp, ISBM I 978-1-4666-4554-7.
3. Carrillo, I., Aguayo, M.G., Valenzuela, S., Elissetche, J.P., 2015: Variations in wood anatomy and fiber biometry of *Eucalyptus globusus* genotypes with different wood density. Wood Research 60(1): 1-10. ISSN 1336-4561.
4. Danihelová, A., 2010: Physics 2. Krupina, Nikara, 206 pp. ISBN 978-80-970363-6-2 (in Slovak).
5. Draxlerová, M., Harangózo, J., Balog, K., 2014: Effects of retardants on the ignition of Woodmaterials. Environmental and Safety Aspects of Renewable Materials and Energy Sources, Advances Materials Research 1001: 288-291, Trans Tech Publications Ltd, ISSN: 1022-6680, ISSN cd: 1022-6680 ISSN web: 1662-8985.
6. Kuklík, P., Kuklíková, A., 2010: Design of timber structures. Guide ČSN EN1995-1, Prague : Information Center ČKAIT, 140 pp, ISBN: 978-80-870938-8-7.
7. Martinka, J., Chrebet, T., 2014a: Activation energy of Teak and Oak wood spontaneous ignition. In: Advanced Materials Research, Switzerland, 1001: 262-266.

8. Martinka, J., Chrebet, T., Hrušovský, I., Balog, K., Hirle, S., 2014b: Fire risk assessment of spruce pellets. Applied Mechanics and Materials 501-504: 2451-2454, © (2014) Trans Tech Publications, Switzerland doi: 10.4028/ www.scientific.net /AMM.) 501- 504.2451, Pp 2451-2454.
9. Martinka, J., Hroncová, E., Chrebet, T., Balog, K., 2014c: The influence of spruce wood heat treatment on its thermal stability and burning process. Eur. J. Wood Prod. 72(4):477-486, DOI: 10.1007/s00107-014-0805-9, ISSN 2042-6445.
10. Martinka, J., Chrebet, T., Kráľ, J., Balog, K., 2013: An examination of the behaviour of thermally treated spruce wood under fire conditions. Wood Research 58(4): 599- 606. ISSN 1336-4561.
11. Mitterová, I., Zachar, M., 2013: The comparison of flame retardants efficiency when exposed to heat. Modern thends in ergonomics and occupational safety. Zielona Góra, University of Zielona Góra. Pp 179-225. ISBN 987-83-7842-286-6.
12. Osvald, A., 1995: The effect of temperature on the physical properties of wood. In: Proceedings Fire and Safety Engineering. Ostrava : VŠB TU Ostrava. Pp 134-138.
13. Osvald, A., 1997: Fire technical properties of wood and wood-based materials: Scientific Study 8/1997/A.: Zvolen, Technical university in Zvolen, 52 pp, ISBN 80-228-0656-0.
14. Osvald, A., 1984: Combustion of wood and wood-based materials. In.: Proceedings of scientific works DF VŠLD in Zvolen 1983–1984. Alfa Bratislava. Pp 197-215.
15. Požgaj A., Chovanec D., Kurjatko S., Babiak M., 1997: Wood structure and properties. Bratislava, Príroda a.s , 488 pp. ISBN 80-0700600-1 (in Slovak).
16. Xu, Q., Que, X., Cao, L., Jiang, Y., Jin, C.A., 2010: Total heat flux on the wall: Bench scale wood crib fires tests. Thermal Science 14(1): 283-290. ISSN 0354-9836.
17. Trebula, P., Klement, I., 2005: Drying and hydrothermal treatment of wood. Zvolen: Technical university in Zvolen, 449 pp, ISBN 80-228-1421-0 (in Slovak).
18. Tsuomis, G., 1991: Science and technology of wood; Structure, properties, utilization. New York: Chapman and Hall, 494 pp. ISBN 0-412-07851-1.
19. Veľková, V., Výbohová, E., Bubeníková, T., 2007 : Negative effect of wood impregnation on environment. Acta Facultatic Ecologiae. Pp 65-70. ISSN 1336-300X.
20. Wagenführ, R., 2007: Holzatlas. Leipzig: Carl Hanser Verlag, 567 pp, ISBN 978-3-446-40649-0.
21. Zachar, M., Marková, I., 2009: Monitoring of difference in thermal degradation of poplar samples (Sledovanie rozdielu v termickej degradácii vzoriek topoľa). Acta Facultatis Xylologiae 51(1): 33-46. ISSN 1336-3824 (in Slovak).
22. Zeidler, A., Šedivka, P., 2015: Influence of selected factors on wood density variability in grand fir (*Abies grandis*/Douglas/Lindl.) Wood Research 60(1): 33-44. ISSN 1336 -4561.

Linda Makovická Osvaldová*, Stanislava Gašpercová, Patrik Mitrenga
Anton Osvald
University of Žilina in Žilina
Faculty of Safety Engineering
Univerzitná 8215/1
010 26 Žilinažilina
Slovak Republic
Corresponding author: Linda.Osvaldova@fbi.uniza.sk