WOOD RESEARCH
58 (4): 2013
599-606

AN EXAMINATION OF THE BEHAVIOUR OF THERMALLY TREATED SPRUCE WOOD UNDER FIRE CONDITIONS

Jozef Martinka, Tomáš Chrebet, Ján Kráľ, Karol Balog
Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology in Trnava
Trnava, Slovak Republic

(Received February 2013)

ABSTRACT

The article deals with determination of impact of thermal treatment of Norway spruce wood (*Picea abies*) on its fire risk. The fire risk of spruce wood was evaluated on the basis of ignition time determination, heat release rate, total heat release and yield of carbon monoxide. Spruce samples were examined in the cone calorimeter at heat flux of 30 and 40 kW.m^{-2}. For research purposes, samples of untreated spruce wood and thermally treated wood at the maximum temperatures of 190 and 212°C in the air atmosphere were used. Given results indicate that thermal treatment cause decrease of ignition time, heat release rate and total heat release. Stated changes are not relevant for the behaviour of observed materials in fire conditions. Thermal treatment significantly influences the yield of carbon monoxide in fire conditions. The yield values strongly depend on external heat flux, by which the examined treated wooden material is loaded in the cone calorimeter.

KEYWORDS: Thermowood, fire characteristics of thermowood, heat release rate, fire risk, cone calorimeter.

INTRODUCTION

Nowadays, we can observe a constant increase in import and use of exotic trees' wood, which happens not just in Slovakia, but practically in the entire European Union. This trend is primarily due to its positive properties. The most valuable properties of exotic trees include high biological resistance (resistance to wood-decay fungi, moulds and insects), resistance to mechanical wear, atmospheric exposure or to fire and also their high aesthetic value. In comparison with domestic timber species there are two main disadvantages, namely a relatively high price (mostly as a result of transportation costs) and higher toxicity of the released dust (mainly the carcinogenic effect).

One way to combine advantages of domestic and exotic timber species is the production of thermally treated wood, which is based on the heat load of wood with a selected temperature program in an oxidising or inert environment. During thermal treatment, wood is warmed up to the temperatures from around 170 to 260°C for a period of several ten hours. The thermal treatment is performed in a gaseous (e.g. air, nitrogen) or a liquid environment (e.g. vegetable oils). The maximum temperature of thermal treatment depends primarily on the environment where it takes place, but it is generally true that the maximum temperature is higher in an inert environment. During thermal treatment, decomposition and elimination of the thermally least resistant components of wood take place (mainly polysaccharides and extractive components).

As a result of the treatment, the wood's resistance to biological degradation and atmospheric exposure as well as its aesthetic value were increased.

Several scientific works engaged with research into effects of thermal treatment of wood on changes in its properties. Marcos et al. (2009) examine the influence of the temperatures of 190, 210, 230 and 245°C on samples of European beech (*Fagus sylvatica*), Scotch pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) in the time intervals of 0, 0.3, 1, 4, 8, 16 hours on their weight reduction and on the overall content of lignin, glucuronoxylan, glucomannan and cellulose in the resistant residue. It is evident from the presented results that the lignin content increases and the content of polysaccharides in the resistant residue decreases, especially in the samples which were exposed to the higher temperatures (230 and 245°C) within the longer time intervals (8 and 16 hours). The glucuronoxylan and glucomannan contents in all three samples which were exposed to the temperature of 245°C within 16 hours were markedly lower compared with the untreated samples. Windeisen et al. (2007) studied the influence of the heat load of European beech (*Fagus sylvatica*) samples on the content of carbon, phenolic and aliphatic hydroxyl groups at the temperatures of 180, 200 and 220°C in 4 to 6 hours. From the presented results, compared with the untreated sample, an increase in the carbon content of the sample exposed to the temperature of 220°C in 6 hours by 6 % is evident. A significant decrease in the portion of the aliphatic hydroxyl groups as well as a significant increase in the portion of the phenolic hydroxyl groups in the thermally treated samples was also noticed. The resistance of thermally treated Jack pine wood (*Pinus banksiana*) to photodegradation caused by solar radiation is closely described by, e. g., Huang et al. (2012). Candelier et al. (2013) define the influence of chemical composition of an ambient environment (nitrogen and vacuum) on the amount of hollocellulose, cellulose, hemicellulose, lignin and extractives in the resistant European beech wood (*Fagus sylvatica*) which was treated with the temperature of 220°C. The presented results refer to a significant decrease in the amount of hollocellulose in the samples thermally treated in a nitrogen atmosphere compared to the samples which were treated in a vacuum. The results of the work of Metsä-Kortelainen et al. (2006) point out the significant decrease in wood's hygroscopicity with increasing temperature of its modification. The decrease in hygroscopicity along with the decomposition of the thermally most unstable polysaccharides has a favourable influence on the increase in resistance of thermally treated wood to moulds. For example, Reinprecht and Vidholdová (2011) deal with this problem more precisely. The decrease in hygroscopicity significantly influences the decrease in the thermal conductivity of thermally treated wood. The problem of the thermal conductivity is elaborated in details by Hrčka and Babiak (2012). The influence of thermal treatment on the ecotoxicity of extractive substances in an aqueous and ethanolic extracts from Maritime pine (*Pinus pinaster*) was examined by Esteves et al. (2011). Presented results indicate that thermal treatment has no significant impact on the increase in the ecotoxicity of extractive substances.

Relatively few works have focused on the evaluation of the influence of thermally treated wood on changes in its fire characteristics. According to Reinprecht and Vidholdová (2011), thermally treated wood shows a lower smoke release rate compared with the untreated wood. Thermally treated wood which was produced in hot vegetable oils has a lower resistance to flame spread according to Wang and Cooper (2007).

The fire risk of a material can be best evaluated on the basis of the heat release rate (Babrauskas and Peacock 1992) and the yield of carbon monoxide under the fire conditions.

The objective of the submitted paper is to evaluate the influence of thermal treatment of Norway spruce wood (*Picea abies*) on the heat release rate and on the yield of carbon monoxide.

MATERIAL AND METHODS

The samples of Norway spruce wood (*Picea abies*) with the dimensions of 100 x 100 x 20 mm (length x width x depth) were used for the research. The samples were divided into 3 groups, each containing 20 pieces. The first group consisted of thermally untreated wood samples. The second group of samples was thermally treated with a thermal program which is applied to the production of ThermoWood – Thermo-S. Firstly, there was heating up from 20 to 100°C within 5 hours and subsequently from 100 to 130°C within 13 hours in the first stage. Secondly, there was heating up from 130 to 190°C within 5.5 hours followed by heating with the constant temperature of 190°C within 3 hours in the second stage. Finally, there was gradual cooling down from 190 to 220°C within 9.5 hours in the third stage. The third group of samples was thermally treated with a thermal program which is applied to the production of ThermoWood – Thermo-D. Firstly, there was heating up from 20 to 100°C within 5 hours and subsequently from 100 to 130°C within 13 hours in the first stage. Secondly, there was heating up from 130 to 212°C within 5.5 hours followed by heating with the constant temperature of 212°C within 3 hours in the second stage. Finally, there was gradual cooling down from 212 to 20°C within 9.5 hours in the third stage. All samples were conditioned to the absolute humidity of 6 % before the actual test. The average density of the thermally untreated samples and the samples before thermal treatment was 340 ± 9 $kg.m^{-2}$. The average density of the samples that had been thermally treated at the temperature of 190°C was 324 ± 7 $kg.m^{-2}$ and the average density of the samples that had been thermally treated at the temperature of 212°C was 317 ± 11 $kg.m^{-2}$. The differences in density were caused by a weight reduction after thermal treatment.

Ignition time, heat release rate and yield of carbon monoxide of the examined materials were determined using the cone calorimeter according to ISO 5660-1:1993. Heat release rate, yield of carbon monoxide and time to ignition were measured at two values of heat flux, i.e. 30 and 40 $kW.m^{-2}$. Each measurement was repeated five times, whereupon the average values are presented as the final results.

A detailed description of the fire characteristics of Norway spruce wood is presented by Zachar et al. (2012).

RESULTS AND DISCUSSION

Fig. 1 illustrates the influence of thermal treatment of Norway spruce wood on the time to ignition at its exposure to external heat flux with the values of 30 and 40 $kW.m^{-2}$.

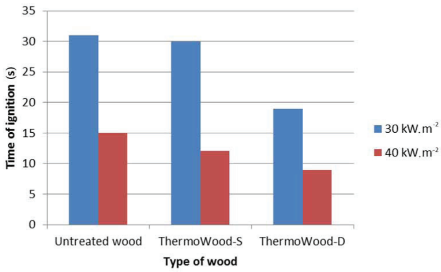

Fig. 1: The influence of heat flux and thermal treatment of Norway spruce wood on its ignition time.

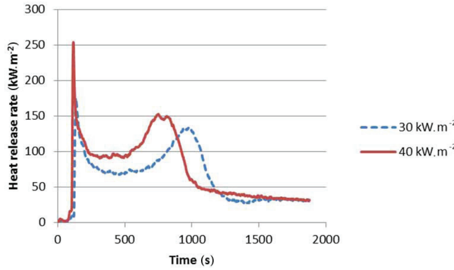

Fig. 2: Heat release rate from untreated wood.

Fig. 2 illustrates the heat release rate of the thermally untreated samples; Fig. 3 illustrates the same physical quantity for termowood treated with the thermal program Thermo-S and Fig. 4 illustrates the heat release rate for termowood treated with the thermal program Thermo-D.

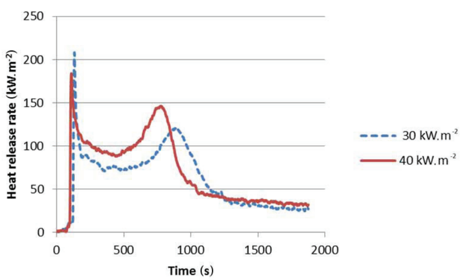

Fig. 3: Heat release rate from ThermoWood-S.

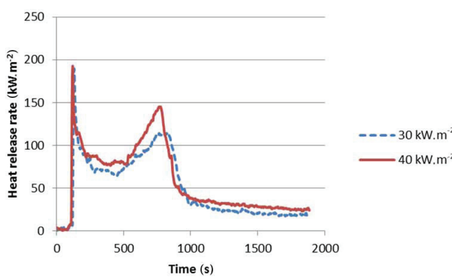

Fig. 4: Heat release rate from ThermoWood-D.

It is obvious already from a visual analysis of the Figs. 2 and 4 that thermally treated Norway spruce wood shows a lower value of the heat release rate peak at the moment of ignition. This is due to the fact that during thermal treatment, the most unstable components of Norway spruce wood (mainly portions of hemicellulose and extractive components) are decomposed.

In case of loading of the wood with an external heat flow, these unstable components release dissociative flammable products which would contribute to an increase in the heat release rate by its own combustion.

A variable, total heat release, during the test duration (30 min.) has been selected for the exact comparison of examined samples in terms of their behaviour in case of fire. The total heat release from the examined samples is illustrated by Fig. 5.

The fire risk assessment of thermally treated wood in terms of toxicity of rising combustion products was performed on the basis of the yield of carbon monoxide, which is toxicologically the most important component of combustion products. The yields of carbon monoxide for the examined materials are illustrated in Fig. 6.

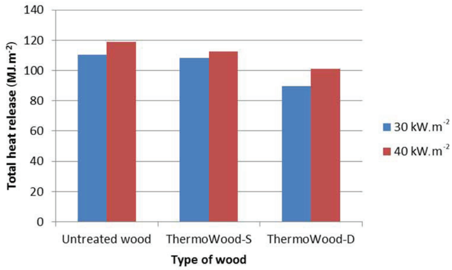

Fig. 5: Total heat release form examined samples.

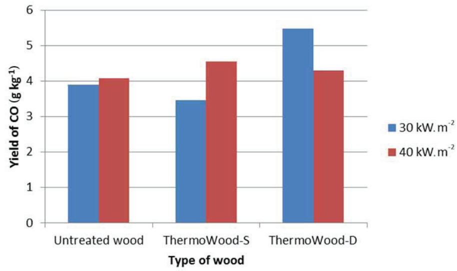

Fig. 6: The yields of carbon monoxide per 1 kilogram of the examined materials.

The decrease in ignition time of thermally treated wood compared with untreated wood was probably due to an increase in the emissivity coefficient of wood during its thermal treatment. Because of the growth of the emissivity coefficient, the ratio of received heat to reflected heat from the cone emitter of the cone calorimeter increased. Thermal decomposition of the thermally least resistant components during thermal treatment of wood could have played an important effect. However, this factor should extend the ignition time according to the opinion generally adopted by experts. The obtained results nevertheless point to the fact that partial decomposition of the thermally most unstable components of wood may rather accelerate the initiation process. A significant decrease in the ignition time with increasing heat flux corresponds to the results published by Martinka et al. (2012a).

The decrease in the heat release rate peak of thermally treated wood was due to the fact that thermally treated wood contains less thermally unstable components, which could release dissociative flammable products in the initiation phase. The courses of the heat release rate themselves of all the evaluated materials were very similar. The first peak arises in the initiation phase of the material and the second one in the phase of flameless combustion (glow). The acquired data are consistent with the scientific works of Martinka et al. (2012b), Xu et al. (2012), Pažitný et al. (2011), Seref and Burhanettin (2010), Ladomerský and Hroncová (2003) and Ladomerský et al. (2003).

The decrease in total heat release was due to a decrease in the content of volatile flammable substances during thermal treatment.

The increase in the yield of carbon monoxide from treated wood was due to an increase in the ratio of carbon content to hydrogen content in the treatment stage. The mentioned matter is due to the fact that carbon monoxide does not directly react with oxygen under the fire conditions, but reacts considerably faster with some hydroxyl radicals. As a result of a decrease in the hydrogen content in wood, the combustion rate of hydrogen also decreases. The aforementioned findings are entirely consistent with the results presented by Balog (1999).

CONCLUSIONS

Thermal treatment of spruce wood influences the decrease in ignition time by radiating thermal flow as well as the decrease in the heat release rate and total heat release during burning. The stated changes are unimportant in terms of material behaviour during the initiation phase as well as in terms of its contribution to fire development. But thermal treatment has a relatively significant influence on the yield of carbon monoxide which is toxicologically the most important component of combustion products of wood materials. The value of the yield of carbon monoxide from thermally treated spruce wood significantly depended on heat flux. Therefore, further scientific works should focus in detail primarily on the impact of heat flux on the yield of carbon monoxide.

ACKNOWLEDGMENT

This article was written thanks to the support in the framework of Operational Programme "Research and Development": Centre for Development and Application of Advanced Diagnostic Methods in Processing of Metallic and Non-metallic Materials, ITMS: 26220120048, co-funded from sources of the European Regional Development Fund.

REFERENCES

1. Babrauskas, V., Peacock, R.D., 1992: Heat release rate: The single most important variable in fire hazard. Fire Safety Journal 18(3): 255-272.
2. Balog, K., 1999: Autoignition. SPBI. Ostrava, 133 pp.
3. Candelier, K., Dumarçay, S., Pétrissans, A., Desharnais, L., Gérardin, P., Pétrissans, M., 2013: Comparison of chemical composition and decay durability of heat treated wood cured under different inert atmospheres: Nitrogen or vacuum. Polymer Degradation and Stability 98(2): 677-681.
4. Esteves, B., Videira, R., Pereira, H., 2011: Chemistry and ecotoxicity of heat-treated pine wood extractives. Wood Science and Technology 45(4): 661-676.
5. González-Peña, M.M., Curling, S.F., Hale, M.D.C., 2009: On the effect of heat on the chemical composition and dimensions of thermally-modified wood. Polymer Degradation and Stability 94(12): 2184-2193.
6. Hrčka, R., Babiak, M., 2012: Some non-traditional factors influencing thermal properties of wood. Wood Research 57(3): 367-374.
7. Huang, X., Kocaefe, D., Kocaefe, Y., Boluk, Y., Pichette, A., 2012: Study of the degradation behavior of heat-treated jack pine (*Pinus banksiana*) under artificial sunlight irradiation. Polymer Degradation and Stability 97(7): 1197-1214.
8. ISO 5660-1, 1993: The cone calorimeter test.
9. Ladomerský, J., Hroncová, E., 2003: Monitoring of suitable conditions of wood waste burning in combustion chamber by emission measurements. (Sledovanie vhodnosti podmienok vyhárania drevného odpadu v spaľovacej komore na základe emisií). Acta Mechanica Slovaca 7(3): 595-600 (in Slovak).
10. Ladomerský, J., Hroncová, E., Samešová, D., 2003: Investigation of appropriate conditions for wood wastes combustion on basis of emission. Drewno 46(170): 90-98.
11. Martinka, J., Balog, K., Chrebet, T., Hroncová, E., Dibdiaková, J., 2012a: Effect of oxygen concentration and temperature on ignition time of polypropylene. Journal of Thermal Analysis and Calorimetry 110(1): 485-487.

12. Martinka, J., Kačíková, D., Hroncová, E., Ladomerský, J., 2012b: Experimental determination of the effect of temperature and oxygen concentration on the production of birch wood main fire emissions. (Experimentálne stanovenie vplyvu teploty a koncentrácie kyslíka na produkciu emisií z horenia dreva). Journal of Thermal Analysis and Calorimetry 110(1): 193-198 (in Slovak).
13. Metsä-Kortelainen, S., Antikainen, T., Viitaniemi P., 2006: The water absorption of sapwood and heartwood of Scots pine and Norway spruce heat-treated at 170°C, 190°C, 210°C and 230°C. Holz als Roh- und Werkstoff 64(3): 192-197.
14. Pažitný, A., Boháček, Š., Russ, A., 2011: Application of distillery refuse in papermaking: Novel methods of treated distillery refuse spectral analysis. Wood Research 56(4): 533-544.
15. Reinprecht, L., Vidholdová, Z., 2011: Thermowood. Šmíraprint. Brno, 89 pp.
16. Seref, K., Burhanettin, U., 2010: Combustion properties of mulberry (*Morus alba* L.) laminated veneer lumbers bonded with PVAC, PF adhesives and impregnated with some fire-retardants. Wood Research 55(2): 99-114.
17. Xu, Q., Majlingová, A., Zachar, M., Jin, C., Jiang, Y., 2012: Correlation analysis of cone calorimetry test data assessment of the procedure with test of different polymers. Journal of Thermal Analysis and Calorimetry 110(1): 65-70.
18. Wang, J.Y., Cooper, P.A., 2007: Fire, flame resistance and thermal properties of oil thermally-treated wood. International research group on wood reservation. Stockholm, 10 pp.
19. Windeisen, E., Strobel, C., Wegener, G., 2007: Chemical changes during the production of thermo-treated beech wood. Wood Science and Technology 41(6): 523-536.
20 Zachar, M., Mitterová, I., Xu, Q., Majlingová, A., Cong, J., Galla, Š., 2012: Determination of fire and burning properties of spruce wood. Drvna Industrija 63(3): 217-223.

Jozef Martinka, Tomáš Chrebet, Ján Kráľ, Karol Balog
Slovak University of Technology in Bratislava
Faculty of Materials Science and Technology in Trnava
Paulínska 16
917 24 Trnava
Slovak Republic
Phone: +421 906 068 531
Correspoding author: jozef.martinka@stuba.sk