Hazards from Burning Impregnated Wood

Subjects: Others

Contributor: Anna Rabajczyk , Maria Zielecka , Daniel Małozięć

In the construction industry, a variety wooden products have been used for thousands of years, according to demand, accessibility/availability, and customers' requirements. Wood is a preferred material due to its large range of properties, depending on the type of wood. It is an easily available and economically competitive material, and also extremely strong in relation to its weight. Therefore, it is used in the production of construction materials, building parts, and finishing components, as well as for furniture and decorative elements. Each of these products is commonly additionally chemically treated to improve its performance parameters. But impregnated wooden products such as furniture and fence boards are often misused, including for house heating, waste incineration, bonfires. etc. For this reason, among the products of combustion there is a whole range of different chemical compounds, frequently carcinogenic, and dangerous for health and the environment, for example heavy metals. Knowledge in this field is important for professions such as: firefighter, lifeguard, people dealing with environmental management, units responsible for waste landfills. On the other hand, important recipients of this information are ordinary residents who, due to a lack of knowledge, use such materials as e.g. heating material.

wood and wooden products impregnations combustion products

1. Introduction

Wooden products are used in every aspect of life. They are used as building and decorative materials, an energy source, or a starting material for the production of other elements. Depending on demand, various types of wood are used, which can additionally be chemically treated.

Wood is an organic material, and is exposed to many harmful biotic and abiotic factors, such as fungi, insects, termites, and external conditions, including damage by water, UV radiation, and fire. In order to protect wooden material from these harmful effects, and to extend its service life, some applications require additional wood protection [1][2]. In addition, the increasing demands placed on products in their field of use, including, e.g., durability, colours, and the possibility of using them for various purposes, mean that products made of wood and appropriately modified, including impregnated goods, are becoming increasingly important on the market. Industrial treatment with protective chemicals compounds is the most-common method of protecting wood from damage. The chemicals used penetrate the wood, which extends the life of the wood and wooden products [1][3][4][5]. However, it should be noted that the compounds used for the impregnation and protection of wood and wood-type products are subject to the legal regulations in force in any given area. In the case of European Union countries, the legal basis in this regard is, for example: Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 on the registration, evaluation, authorisation and restriction of chemicals (REACH) covered by the

European Chemicals Agency, the changing requirements of 1999/45 / EC and repealing Council (EEC) No 793/93 and Commission (EC) No 1488/94, as well as Council Directives 76/769 / EEC and Commission Directives 91/155 / EEC, 93/67 / EEC, 93/105 / EC and 2000/21 / EC, Regulation (EU) No 528/2012 of the European Parliament and of the Council of 22 May 2012 concerning the making available on the market and use of biocidal products.

However, biocidal products can affect not only harmful organisms, but also humans, the environment, and endangered species. The active substances can be carcinogenic, toxic to reproduction, or disruptive of the endocrine system. Children and pregnant women are particularly vulnerable [6]. In addition, each country has its own internal rules and regulations, including requirements for approvals, certification, and products' technical approvals to which manufacturers have to comply. The requirements relate to issues of the safe use of agents, their stability, and the reactivity, quantitative, and qualitative characteristics, and toxicity.

2. Chemism of wooden materials

Wood consists, by total weight, of over 99% organic substances, including cellulose, lignin, and hemicellulose. Absolutely dry wood, on average, contains 49% carbon, 44% oxygen, 6% hydrogen, and 0.1-0.3% nitrogen [7]. The rest comprise inorganic compounds, consisting of calcium, potassium, sodium, magnesium, and other elements. Polysaccharides, such as cellulose and hemicellulose, and lignin, belong to biopolymers, with varying degrees of polymerisation. Thus, they are characterised by different properties, both chemical and physical. Cellulose creates microfibres, among which are lignin, hemicellulose, and water.

In addition to basic organic substances, natural wood, depending on the species, also contains a relatively small amount of extractive substances, such as tannins, resins, pectins, fats which are soluble in water, alcohol, and ether. The pine and spruce walls of wooden houses contain active substances such as phytocides, which can protect humans against fungi, bacteria, and viruses, and thus against infectious diseases [8].

Diverse requirements in the scope of the quality and durability of wood, as well as the diversity of wood species which require various modes of handling, mean that a whole range of different substances are available on the market. For example, to protect the structural wood against insects, fungi, and fire, salt impregnations are used for protection against moisture, UV rays, and pests; solvent preparations and colouring impregnating agents are fungicides and insecticides; while water-borne impregnations allow protection against moisture, insects, and microorganisms. In order to improve properties in the field of the reaction to fire there are used, e.g., boron compounds, while, to protect wood against fungi, insects, and termites, active substances such as copper and chromium are employed.

Substances such as ammonia salts, phosphorus, and boron compounds are added to reduce the flammability of wood. Paraffin, styrene, methyl methacrylate, and isocyanate, all materials which increase dimensional stability and improve hydrophobic efficiency, affect the flammability of wooden products, resulting in an enhancement to this parameter [1][9][10]. Impregnates such as TiO_2, WO_3 or $CaSiO_3$ penetrate the structure of the wood and fill the pores and areolate pits, which affects both the amount of water absorbed in the equilibrium state and the kinetics of water

sorption [11]. One of the substances used to impregnate wood is creosote, a mixture made of coal tar, consisting of, inter alia, compounds from the group of phenols, cresols and xylenols, in various ratios, depending on the production process used [12]. Copper particles that are found in impregnating agents such as Micronised Copper Azole (MCA) and Micronised Copper Quaternary (MCQ) accumulate in the wood [13].

Alternatives to chemicals, intumescent coatings containing bio-fillers, bio-based substances, such as ginger and coffee husks, egg shells, molluscs, tea saponin, organically modified montmorillonite (MMT), are being developed [14].

3. Flaming and smouldering combustion processes

Wooden and wood-like, wood-based, products emit various compounds into the environment, the composition of which depends on the type and chemical composition of the material, as well as external factors, including temperature, oxygen access, and the presence of other substances, such as radicals and catalysts. All these elements determine the type of combustion process, which can include processes such as smouldering (flameless combustion), or combustion with the production of flame (flame combustion). Flameless combustion, e.g. smouldering, is one of the slow processes occurring under relatively low temperature conditions, and is the most persistent type of combustion phenomenon, characterised by the absence of a flame, and is therefore a threat to safety and the environment. Smouldering is one of the main causes of death in apartment fires, and a source of safety concerns in workplaces and other situations in which biomass and peat are burned, which causes environmental degradation [15][16][17][18][19]. As smouldering is a slow and sustained process, smouldering fires can lead to increased heat transfer and pollutants' entering the soil over a much longer period of time [17][18][19]. In the case of a smouldering front's moving in the direction of the oxidant flow, the fresh oxidant flows through the charred layer and reacts in the ignition zone, which causes oxidation reactions to occur at the rear of the ignition zone, and pyrolysis at the front. In the reverse situation, the oxidant travels through the primary fuel and reacts in the smouldering zone. As a result, both oxidation and pyrolysis reactions occur approximately in the same place [20]. Both smouldering and flame-burning combustion have a genesis from the same process as pyrolysis.

It should be remembered that for each solid material, both smouldering and flame combustion can occur, and also one process can lead to another [15][16][17]. Under specific conditions, rapid oxidation can develop, and in a very short time, i.e. an explosion.

Flame combustion is associated with the combustion process of the flammable volatile phase, and takes place during the combustion of substances that turn volatile during heating. This phenomenon is characteristic mainly for organic materials which decompose due to increases in temperature, and produce flammable vapours and gases. Burning gases and vapours above the surface of combustible material create a flame.

Depending on the stage, compounds are emitted which have a different chemical nature and biological activity, and thus various kinds of impact on humans and the environment. Scattered small gaseous and solid particles result from the combustion of organic materials, giving their characteristic colour, smell, taste, density, and toxicity, and

their ability to penetrate and move in the environment, and create smoke. In the case of the same wooden products, but impregnated with other chemicals, other substances, more or less toxic, will be discharged into the environment. Therefore, smoke in blue, white, or yellow colours, with a bitter or sweet taste, indicates the presence of poisonous substances. Combustion products include volatile combustion substances such as carbon oxides, methane, hydrogen, hydrogen sulphide, and sulphur dioxide, and solid combustion products such as soot, ash, and slag, which differ in composition and properties.

It should be noted that used and waste wood impregnated by various chemical compounds is classified as hazardous waste and requires appropriate handling. Combustion is possible only in properly prepared installations due to the emission of hazardous substances. However, the emission of combustion products of wood impregnated with various chemical compounds is related not only to the inappropriate handling of wood as waste. The risk is also associated with situations of uncontrolled combustion, such as fires. And the next chapter in this study shows why it is so important to properly handle this type of material.

4. Emission of pollutants and methods of measurement

The characteristics of emitted pollutants generated during the combustion of impregnated wood depend on the type of impregnate and the burning conditions. As is known, much larger amounts of toxic gases, including CO, are emitted during the smouldering combustion process of non-treated wood compared to the flaming combustion of such wood [21]. During incomplete wood burning, in addition to CO, other combustion products - methanol, formaldehyde and acetic acid - are released, as well as more complex products derived from the depolymerisation of the lignocellulosic structures of wood [22]. Depending on the type of wood, polycyclic aromatic compounds (PAH) [23][24], polychlorinated biphenyls (PCB) [25], polychlorinated dibenzo-p-dioxins (PCDD), and polychlorinateddibenzofurans (PCDF) [24][25][26][27] can also be released.

Depending on the type of impregnate, various reactions can take place during combustion processes, including those catalysed by metal ions and atoms contained in the impregnate, especially those intended to protect against microbial and fungal attack. The effect of the various combustion conditions during flaming and smouldering combustion processes of impregnated wood on the composition of combustion products is evident.

Due to the pyrolysis of CCA-treated wood, arsenic is already released at 320 ºC. It was also found that, although arsenic is present in wood in a five-valued state, As(III) is present in the pyrolysis residue. The presence of wood, charring and pyrolysis vapours thus influences the thermal behaviour of nitrogen oxides [28].

Keskin et al. [29] found that the type of impregnation determines the method of combustion, including the burning time, and the presence or absence of a flame or glow; thus, also the products of combustion. All ammonium salts are possible sources of ammonia [30].

Fires in wood impregnated with copper-based preservatives can increase the amount of PCDD/F. The formation of PCDD and PCDF during fires is favoured by low-temperature combustion with limited oxygen supply. It has been

found that copper is constantly the most effective metal for catalysing the formation of PCDD and PCDF.

The formation of PCDD and PCDF is favoured at low temperatures conducive to smouldering, especially in the case of reduced oxygen access from the air.

5. Conclusions

Impregnated wood is commonly used in building interiors, both as a building material and as finishing, decorative, and utility elements. Impregnation agents contain in their composition organic compounds, carboxylic acids, esters, and inorganic compounds, including mainly heavy metals such as Cu, Zn, and Cd. The variety of impregnating compounds means wooden and wood-based products may be used in various conditions, outside and inside buildings. They reduce the risk of fire hazards in standard conditions by changing the pyrolysis process, and reduce material degradation under the influence of water, sunlight, microorganisms, or other factors. However, this diversity determines the potential risk in the event of using impregnated wood as an energy material, or if there is a fire. Compounds added to wood as a result of high temperatures undergo thermal changes, releasing toxic carcinogenic compounds.

It should be noted that there are not enough research results in the literature that would allow the conclusion that the issue of the effect of burning wood material depending on the substances used for impregnation has been thoroughly understood. However, due to the potential threat to humans and the environment in the event of fire from impregnated-wood materials, it is necessary to gather knowledge of the mechanisms of thermal degradation, the combustion efficiency of impregnated-wood material, and the volume of emissions of combustion products. Knowledge in this field will facilitate the development of the necessary tools to increase security and take the appropriate precautions. The knowledge about chemical compounds, the combustion conditions and amounts of emission as well the affect of these compounds on humans and the environment, is indispensable. It allows for proper preparation of a rescue operation, securing, and developing protective measures that minimize the risk.

References

1. Can, A.; Özlüsoylu, İ.; Grzeskowıak, W.; Sözen, E. Improvement of Fire Performance of Impregnated Wood with Copper Based Chemicals. Implementation of Wood Science in Woodworking Sector. 28th International Conference on Wood Science and Technology 2017. Proceedings, Zagreb 7-9 December 2017.
2. Baysal, E.; Deveci, I., Turkoglu, T., Toker, H. Thermal analysis of oriental beech sawdust treated with some commercial wood preservatives. Maderas. Ciencia y tecnología 2017, 19(3), 329-338.
3. Ahmed, S.A.; Morén, T. Moisture properties of heat-treated Scots pine and Norway spruce sapwood impregnated with wood preservatives. Wood and Fiber Science 2012, 44(1), 85-93.

4. Ajuong, E.; Pinion, L.C. Corrosion and degradation of engineering materials. In Shreir’s Corrosion, ed. Richardson, T.J.A., Elsevier Science Ltd, 2010, pp. 2439-2446.
5. Sandberg, D.;Kutnar, A.;Mantanis, G. Wood modification technologies - a review. iForest 2017, 10, 895-908. doi: 10.3832/ifor2380-010)
6. Regulation (EU) No 528/2012 of the European Parliament and of the Council of 22 May 2012 concerning the making available on the market and use of biocidal products Text with EEA relevance. The Biocidal Products Directive (BPD 98/08/EC).
7. Mačiulaitis, R.; Jefimovas, A.; Zdanevičius, P. Research of natural wood combustion and charring processes. J Civ Eng Manag 2012, 18(5), 631-641. DOI: 10.3846/13923730.2012.720935
8. Franco, L.S.; Shanahan, D.F.; Fuller, R.A. A Review of the Benefits of Nature Experiences: More Than Meets the Eye. Int J Environ Res Public Health 2017, 14(8), 864. https://doi.org/10.3390/ijerph14080864
9. Popescu, C.-M.; Pfriem, A. Treatments and modification to improve the reaction to fire of wood and wood based products - An overview. Fire and Materials 2020, 44(1), 100-111. DOI: 10.1002/fam.2779
10. Ali, S.; Hussain, S.A.; Tohir, M.Z.M. Fire Test and Effects of Fire Retardant on the Natural Ability of Timber: A Review. Pertanika J. Sci. & Technol. 2019, 27(2), 867 – 895
11. Croitoru, C.; Patachia, S.; Lunguleasa, A. New Method of Wood Impregnation with Inorganic Compounds Using Ethyl Methylimidazolium Chloride as Carrier. J. Wood Chem. Technol. 2015, 35:2,113-128, DOI: 10.1080/02773813.2014.892991
12. Melber, C.; Kielhorn, J.; Mangelsdorf, I. Coal Tar Creosote (Report). United Nations Environment Programme, International Labour Organization, and World Health Organization, 2004.
13. Platten, W.; Luxton, T.; Gerke, T.; Harmon, S.; Sylvest, N.; Bradham, K.; Rogers, K. Release of Micronized Copper Particles from Pressure Treated Wood Products. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-14/365, 2014.
14. Aqlibous, A.; Tretsiakova-McNally, S.; Fateh, T. Waterborne Intumescent Coatings Containing Industrial and Bio-Fillers for Fire Protection of Timber Materials. Polymers 2020, 12, 757. doi:10.3390/polym12040757
15. Ahrens, M. Home Structure Fires. Report: NFPA's "Home Structure Fires", National Fire Protection Association (NFPA), October 2019, pp.18.
16. Rein, G. Smoldering combustion, in SFPE Handbook of Fire Protection Engineering, eds Hurley, M.J.; Gottuk, D.; Hall, J.R.; Harada, K.; Kuligowski, E.; Puchovsky, M.; Torero, J.; Watts, J.; Wieczoreks, C. New York, NY, Springer New York, 2016, pp. 581–603.

17. Santoso, M.A.; Huang, X.; Prat-Guitart, N.; Christensen, E.; Hu, Y.; Rein, G. Smouldering fires and soils, Chapter 13, in Fire effects in soil properties, ed Pereira P.; Clayton, VIC: CSIRO, 2019, pp. 203–216.
18. Watts, A.C.; Kobziar, L.N. Smoldering Combustion and Ground Fires: Ecological Effects and Multi-Scale Significance. Fire Ecol 2013, 9, 124–132. https://doi.org/10.4996/fireecology.0901124
19. Neary, D.G.; Ryan, K. C.; DeBano, L.F., eds. Wildland fire in ecosystems: effects of fire on soils and water. Gen. Tech. Rep. RMRS-GTR-42-vol.4. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 2005 (revised 2008), pp. 250.
20. Shrivastava, P.; Baweja, C.; Nalawade, H.; Kumar, A.V.; Ramanan, V.; Malhotra, V. An Experimental Insight into the Smoldering-Flaming Transition Phenomenon, Journal of Combustion 2017, ID 4062945, pp. 12. https://doi.org/10.1155/2017/4062945
21. Stec, A.; Hull, R. Fire Toxicity, Woodhead Publishing Ltd, 2010, pp. 688.
22. Schauer, J.J.; Kleeman, M.J.; Cass, G.R.; Simoneit, B.R.T. Measurement of emissions from air pollution sources. 3. C1–C29 organic compounds from fireplace combustion of wood. Environ Sci Technol 2001, 35, 1716–1728. https://doi.org/10.1021/es001331e
23. Zou, L.Y.; Zhang, W.; Atkiston, S. The characterisation of polycyclic aromatic hydrocarbons emissions from burning of different firewood species in Australia. Environ Pollut 2003, 124, 283–289. https://doi.org/10.1016/s0269-7491(02)00460-8
24. Gullett, B.K.; Touati, A.; Hays, M.D. PCDD/F, PCB, HxCBz, PAH, and PM emission factors for fireplace and woodstove combustion in the San Francisco bay region. Environ Sci Technol 2003, 37, 1758–1765. https://doi.org/10.1021/es026373c
25. Gullett, B.K.; Touati, A.; PCDD/F emissions from burning wheat and rice field residue. Atmos Environ 2003, 37, 4893–4899. https://doi.org/10.1016/j.atmosenv.2003.08.011
26. Launhardt, T.; Strehler, A.; Dumler-Gradl, R.; Thoma, H.; Vierle, O. PCDD/F- and PAH-emission from house heating systems. Chemosphere 1998, 37, 2013–2020. https://doi.org/10.1016/S0045-6535(98)00265-3
27. Pfeiffer, F.; Struschka, M.; Baumbach, G.; Hagenmaier, H.; Hein, K.R.G. PCDD/PCDF emissions from small firin systems in households. Chemosphere 2000, 40, 225–232. https://doi.org/10.1016/S0045-6535(99)00307-0
28. Helsen, L.; Van den Bulck, E.; Cooreman, H.; Vandecasteele, C. Development of a sampling train for arsenic in pyrolysis vapours resulting from pyrolysis of arsenic containing wood waste. J. Environ. Monit. 2003, 5, 758-765
29. Keskin, H.; Ertürk, N.S.; Çolakoğlu, M.H.; Korkut, S. Combustion properties of Rowan wood impregnated with various chemical materials. 2013, 8(19), 1022-1028. DOI: 10.5897/IJPS12.690

30. Vargun, E.; Baysal, E.; Turkoglu, T.; Yuksel, M.; Toker, H. Thermal degradation of oriental beech wood impregnated with different inorganic salts Maderas, Cienc. Tehcnol. 2019, 21(2) http://dx.doi.org/10.4067/S0718-221X2019005000204