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IMPREGNATED WOOD THE END OF LIFECYCLE-OPTIONS TO CONTRIBUTE TO MATERIAL REUSE

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Abstract:

Wood material’s vulnerability to natural degradation has necessitated the use of impregnation agents, such as arsenic, chromium, and creosote, the application of which is now relatively contentious due to modern knowledge. Particularly from a sustainability perspective, the impregnation of treated wood material requires accurate treatment at the end of the product lifecycle. This study reviews various appropriate treatment options for impregnated wood at the end of the product lifecycle. Various biological treatment options are considered as alternative routes for these materials as well as technological solutions for material identification including X-ray fluorescence (XRF) and laser-induced breakdown spectroscopy (LIBS) technologies. The proposed alternative routes are functional in some respects but are not perfect; thus, technological solutions appear to represent a more realistic way to attend to impregnated wood. Available methods and technologies have been improved with advanced applications but cannot achieve perfect results, indicating a need for future research.

Key words: *impregnated wood; CCA; XRF; LIBS; re-use; recycling.*

INTRODUCTION

Due to wood’s universally well-known favorable material properties, such as excellent weight-strength ratio and easy workability, it has attracted material use in several applications. In addition, wood has represented a highly sustainable material option for various structures due to its carbon storage feature, and wood construction can reduce greenhouse gas (GHG) emissions (Brashaw and Bergman 2021). However, the average natural durability of the material has presented a challenge especially in outdoor applications that partly limit the use of natural wood material. These durability features have been improved with various solutions over the decades such as by impregnation, in which the material substance is filled by impregnation preservatives. Impregnation is also a traditional wood modification method, wherein the wood material substance is filled by an inert material, providing a desired performance change (Hill 2006). In the case of impregnation modification, an important recommendation for wood modification is that no hazardous residues should be contained in the wood once the modification process is complete so that the product may be disposed at the end-of-life stage without the presence of environmental hazards beyond those of unmodified wood (Sandberg et al. 2017). Despite this recommendation, wood impregnation has been traditionally performed with toxic agents that require attention at the product end-of-life stage.

The combination of vacuum and pressure treatments allows the deep penetration of impregnation agents with good retention. The most common methods are the Bethell, Lowry, and Rueping (Rüping) methods, with the former method known as a full cell treatment and the latter two known as empty cell treatments. Some other generally accepted methods include vacuum treatment and the oscillating pressure

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method (Archer and Lebow 2006). Traditional impregnation agents have often also been called wood preservatives, which as stated by Kirker and Lebow (2021), can be classified into two classes: oil-type and waterborne preservatives. The most well-known waterborne preservative is perhaps chromated copper arsenate (CCA), a mixture of chromic acid, cupric oxide, and arsenic pentoxide, which was the dominating wood preservative in the treated wood market until the beginning of the 2000s. The use of CCA was superseded by harmless agents after human health concerns regarding CCA were recognized especially with respect to arsenic and hexavalent chromium, which are both potential human carcinogens. The concentrations varied in CCA-treated wood, but the study of Townsend et al. (2003) was recognized the arithmetic mean concentrations of arsenic, chromium, and copper as follows; 28.5, 31.1, and 37.2mg/kg, respectively. Nowadays, particularly in Europe, copper is often used as a biocide in various wood preservative solutions. Due to the tolerance of copper recognized in some fungi, preservative solutions often include a co-biocide such as an ammonium compound, triazole, amine, or polymeric betaine. Borate compounds are also used to protect wood. Corresponding with oil-type wood preservatives, the most commonly known agent is a creosote that is a mixture of polycyclic aromatic hydrocarbons (PAHs), tar acids, and tar bases. Due to the mentioned components and oily surface, creosote and its solutions are not the primary choices for solutions requiring human contact; its use is better known in industrial activities, such as in poles and railroads (Archer and Lebow 2006, Kirker and Lebow 2021).

There has been a lot of debate regarding the idea of materials circular economy in the last few years as well as regarding the safety of recycling treated wood material. The reutilization and recycling of impregnated wood are controlled by several regulations in Europe due to the hazardous nature of various agents, such as arsenate, chromium, and creosote as previously mentioned, and the preservative CCA has been banned since 2007 in Europe (European Commission 2006a). Since then, CCA-treated wood has only been accepted on the market for professional and industrial use. Details regarding the use of CCA solution treated wood were described in the regulation of the European Parliament and Council known as REACH (Registration, Evaluation, Authorization, and Restriction of Chemicals) (European Commission 2006b). In addition to REACH, the after-use of impregnated wood has been controlled by various regulations, such as the Basel Convention and extended producer responsibility (EPR). The Basel Convention prevents the export of hazardous wood material from developed countries to developing countries (Yang 2020) and EPR instructs producers of products on organizing and funding management systems for waste products until their final disposal. The EPR rule has been defined more specifically nationally, such as by the Finnish Waste Act (Waste Act 2011). However, in some countries such as Finland, EPR for impregnated wood is not regulated by law; rather, the producer responsibility of organizations operates in accordance with voluntary producer responsibility, which regulates the recycling of impregnated wood (Kestopuuteollisuus 2022a). In addition to the mentioned widely valid regulations, national rules control the after-use of treated wood at the earlier stages of waste hierarchy, such as in the case of energy recovery. For example, arsenate treated CCA wood cannot exceed arsenate levels of over 6 ng/m^3 in the air, as a yearly average value (Government Decree 2017). Furthermore, the arsenate and chromium content in the waste material in landfill is restricted to limits of 25 mg/kg and 70 mg/kg, respectively (Government Decree 2013). The described limited values demonstrate the impropriety of CCA-treated wood for landfill, and necessitate exact identification analyses for material composition.

OBJECTIVE

In Finland, the production of impregnated wood was approximately 342 000m^3 in 2020, the majority comprising impregnated sawn timber (280 000m^3) and minor shares of poles and crossties amounting to some tens of thousands of cubic meters (Järvinen et al. 2022). Production levels have remained the same throughout the 21st century (Kestopuuteollisuus 2022b); thus, these materials are available on the market now and in the future, highlighting the need for the improvement of effective material reuse and recycling methods. A particularly important topic is the reliable and effective analysis and identification of materials. The aim of this study is therefore to investigate various existing methods for the analysis of impurities in materials. In addition, this study assesses various options for material reuse.

ALTERNATIVE OPTIONS FOR IMPREGNATED WOOD TO ELIMINATE HARMFULNESS

The traditional options for disposing treated wood material include energy recovery and partial recycling at the end-of-life stage, which can also become options for impregnated wood. In light of the aforementioned presented restriction surrounding impregnation modifiers, various innovative alternative options have been studied regarding the safe disposal of impregnated wood, such as absorption, bacteria, and fungi treatment for CCA wood material.

Various absorption materials and methods such as carbon, yeast, and barks have been studied for use in the compensation of harmful matter. For example, up to 60% of copper can be removed from wood material through absorption by baker’s yeast, oak bark, or apple peels. By contrast, chromium removal has proved to be a challenge (Kartal et al. 2008). Absorption using chitin and chitosan was studied wherein 74% and 57% of copper could be removed from impregnated wood material, respectively: however, deletion levels of chromium and arsenic were minor compared with the presented example of copper (Kartal & Imamura 2005). Compared with the presented absorption methods, better results for removing harmful agents from treated wood were achieved via a two-stage bacterial treatment. Treatment with bacteria (*L. bulgaricus* and *S. thermophilus*) removed copper, chromium, and arsenic from wood dust by 93.0, 86.5, and 97.8%, respectively, after 4 days of extraction (Chang et al. 2012). Fungal bioleaching represents a promising option for superior results. Arsenic and chromium content can be removed from CCA-treated wood via the utilization of fungus, while its combination with acid can also remove copper. A treatment combination of citrus acid dissolution and fungus resulted in perfect arsenic removal, and 87% of copper and 80% of chromium could be removed using the same method (Sierra-Alvares 2009).

In addition to the previously presented methods, various other methods have been studied, such as the combination of oxalic acid extraction and sequential electrokinetic treatment for harmful materials (Isosaari et al. 2010) as well as various chemical treatments. Overall, these methods may be too expensive and time-consuming for effective use, and both successful and cost-effective processes have not yet been innovated based on the existing hypotheses. A common conclusion among most of the previously presented methods was that these methods create some amount of byproduct which can be classified as waste and also requires solutions for its sustainable use. Technologies that can identify harmful agents are therefore both necessary and justifiable; thus, they are discussed in more detail in the following section.

ANALYSIS OPTIONS FOR IMPREGNATED WOOD MATERIAL

The literature presented in this review demonstrates two feasible analytical techniques for the analysis of impregnated wood: X-ray fluorescence (XRF) and laser-induced breakdown spectroscopy (LIBS). This study focused on technologies in for the application of field analytical chemistry (FAC) that aim to reduce analysis time and costs on-site; collection and transport times are not addressed.

XRF spectroscopy technology is traditionally known as a laboratory-based method, but it can also be adapted for portable use. The general advantages of XRF use are minimal sample preparation with fast and non-destructive analysis, as well as good precision and accuracy. A disadvantage of XRF is unknown penetration depth (Hou and Jones 2000); however, in the case of impregnated wood, this is not a significant concern because the potential prominent substances are located mainly on the material surface. Nevertheless, the distance between the XRF detector and the wood sample cannot be over 150 cm (Hasan et al. 2011) and thus, it be usually placed below the conveyor in the industrial applications. XRF has proved to be an effective method for the identification of arsenic in CCA wood, but it is critical to increase the acceptable distance between the detector and sample (Solo-Gabriele et al. 2004). Overall, in the case of CCA wood, a full-scale system can achieve sorting efficiencies for metals of 75-99%. Copper detection is especially challenging for XRF; in one study, it was found that XRF could only detect copper in a solution with the presence of copper preservatives such as alkaline copper quat (ACQ) (Hasan et al. 2011).

Advanced methods on the market, based on XRF technology include energy dispersive XRF (EDXRF) and wavelength dispersive XRF (WDXRF) in which the detector analysis is more versatile compare with traditional XRF. With respect to the EDXRF spectrometer, an energy dispersive detector can detect different released fluorescence energies from a sample together with an X-ray tube. The specialty of the WDXRF spectrometer is its utilization of two types of elements simultaneously; while observing, a crystal or monochromator diffracts the various energies of the sample's characteristic radiation in many directions (XOS 2023). Typically, the WDXRF has a lower resolution compared with the EDXRF, which minimize spectral overlap and allows for the more efficient categorization of data, but it is also more costly.

The LIBS technique analyses the surface of a sample using a laser beam that is focused onto a target material. After the laser irradiance exceeds the material breakdown threshold, a transient and energetic plasma is formed. The emitted radiation can be spectrally resolved, and the intensity of the spectral lines can be measured (Hou and Jones 2000). Coated surfaces have previously represented a challenge to chemical identification, but current LIBS systems can identify the presence of chemicals in such surfaces (Solo-Gabriele et al. 2004). In the case of impregnated wood, several studies using the LIBS method have been performed over the decades, such as those by Moskal and Hahn (2002), Martin et al. (2005) and Mauruschat et al. (2016). It has been found that LIBS can successfully assess the inorganic composition of wood products (Martin et al. 2005); for example, in one study, the accuracy of LIBS was over 90% for CCA and untreated wood differentiation from the stream of construction and demolition waste (Moskal and Hahn 2002). In addition to CCA, chromium–copper–boron (CCB) compounds have also been effectively identified in treated wood using LIBS, and a study by Martin et al. (2005) showed potential for identifying elements from ammoniacal copper zinc (ACZA) and alkaline copper quat (ACQ) preservatives.

Identification results depend on several factors; the heterogenous nature of wood may cause some speculation regarding these methods' functionality. For example, differences between heartwood and sapwood have been noted as well as differences due to the presence of knots (Hasan et al. 2011). However, the moisture content of impregnated wood does not have a significant on the functionality of XRF (Dubey et al. 2007). The reviewed studies did not demonstrate the perfect identification of materials; for instance, copper can currently only be recognized at accuracy levels between 75 and 95% (Hasan et al. 2011). Thus, technologies still require future development and economic analysis must be included in the assessment of their use.

DISCUSSION

Impregnated wood has great significance in Northern Europe, whose countries account for approximately one-third of the total European impregnated wood market supply, for example Sweden is a significant producer of pressure-treated wood (Salminen et al. 2014). Thus, solutions for the end-of-life use of impregnated wood should be analyzed in Nordic areas so that they may pave the way for sustainable material use. Based on the study, alternative options (bacteria and fungi treatments) can be used to eliminate the harmfulness of materials, but the perfect treatment combination to eliminate all the hazardous elements in wood material is not yet available. Material identification is therefore an essential task wherein harmful matter can be identified and handled based on its specific needs without all material being assigned for end-of-life treatment. The identification methods and analysis are individual depending on the method, but critical requirements for wood material is not necessary. For example, quite small size sample can be accepted and XRF method was able to recognize the impregnated sample even wood sample is coated with paint or dye (Solo-Gabriele et al. 2004).

CONCLUSION

The reutilization of wood materials is becoming increasingly important nowadays in response to public demand for the sustainable use of resources. It is widely accepted that harmful wood materials should be recycled according to specific treatment routes, and the number of alternative methods is currently quite low, meaning that logistic costs may represent a relatively high share of the total treatment cost. According to the existing waste policy, waste prevention is the most recommended of sustainable solutions, but reuse represents the second most preferred option. One potential method for the reutilization of wood material is to use it as a raw material in the structure of composites. This could also present a solution for impregnated wood at the end of the product lifecycle, but its safety aspects must first prove viable. If the safe reuse of impregnated wood material can be demonstrated, raw material reuse in composites could be accepted as a sustainable material solution of the future.

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