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Evaluation of the state of preservation of waterlogged archaeological wood based on its physical properties: basic density vs. wood substance density

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ABSTRACT

The state of preservation of waterlogged archaeological wood was evaluated on the basis of the maximum moisture content (MMC), the basic density (BD) and the wood substance density (WSD) determined in water and helium. The degree of wood degradation was compared under the criteria: the loss of wood substance (LWS) and the loss of wood substance density (LWSD). Studies were conducted on the wood samples differing in species, degree of degradation, age and place of origin. The physical properties of wood were determined for the material containing mineral compounds and the material without minerals. The properties of the latter, in which the minerals are replaced by water, were calculated from the mass and volume of the wood containing minerals as well as the content and density of the ash obtained after burning the sample.

The study revealed the effect of minerals on the tested parameters and wood degradation indices. A strong relationship between BD and MMC was confirmed for both the wood containing minerals and without them, by contrast a substantially weaker correlation between BD and WSD was observed. It was found that the assessment of the state of wood preservation conducted on the basis of LWS and LWSD yielded different results. In addition, it was revealed that both indices of wood degradation might be unreliable. The main drawback of the LWS-based assessment is associated with a wide range of basic density of fresh wood. In turn, the LWSD mainly indicates the changing ratio of the carbohydrates/lignin content, but fails to provide information on the loss of wood substance. This may hinder the comparison of the wood sampled from different sites and subjected to different decay mechanisms. Nevertheless, the WSD-based assessment of the state of preservation of waterlogged archaeological wood might be a valuable complementary method to the BD- and/or MMC-based assessment, which is routinely carried out in many conservation centers.

1. Introduction

The state of preservation of waterlogged archaeological wood is evaluated mainly for the selection of an appropriate method for its conservation. Such a test is performed also in the case of monitoring the ongoing rate of degradation of wood tissue. The degree of wood decomposition can be determined on the basis of its physical and chemical properties as well as by microscopic observations (Babiński, 2005; Capretti et al., 2008; Gregory and Jensen, 2006; Hoffmann et al., 1986; Hoffmann and Parameswaran, 1982; Macchioni et al., 2012; Passialis, 1997; Pizzo et al., 2013; Schniewind, 1990). In many conservation laboratories, evaluation of the state of preservation of archaeological wood tissue is most often based on the physical properties of the wood, related to its mass and volume. This is because it is a simple research method and considerable repeatability of the results can be obtained. The fact that the choice of a method of conservation of waterlogged archaeological wood is mainly based on its physical properties should not be underestimated. Such a procedure has been widely described in many publications, which makes it a valuable source of information for conservators of monuments. On the other hand, no detailed procedures have yet been worked out to enable choosing an appropriate method for dimensional stabilization and strengthening of wood on the basis of the results of its chemical and/or microscopic analyses.

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Usually, in order to evaluate the degree of degradation of waterlogged wood its maximum moisture content and basic density are considered. To a much lesser extent, decay of the objects to be conserved is evaluated on the basis of wood density in waterlogged condition or porosity (Donato and Lazzara, 2012; Hoffmann and Blanchette, 1997; Mikolaychuk, 1997). However, the application of wood substance density for that purpose has not often been observed.

It is widely acknowledged that the mass and volume of wood substance forming the cell walls decreases as the wood decay develops. This process results in a decrease in basic density and wood density in wet condition, as well as an increase in porosity and maximum moisture content. There are strict dependences between all those properties, described in many handbooks on wood science. Practical guidelines for determining the physical properties of waterlogged archaeological wood and the dependences between them were presented in detail by Jensen and Gregory (2006).

However, wood is a material the properties of which vary not only with the degree of decomposition of its cell walls. The physical properties of fresh wood depend not only on its species, but also on the sampling place (trunk, branches and roots; sapwood and heartwood; juvenile and mature wood). Significant variation of the properties under discussion was also noted depending on the conditions pertaining to the tree growth, including its biosocial position in the woodland stand (Fabisiak, 2005). One should also not underestimate changes that appear in wood with certain natural defects (e.g. knots, reaction wood). At the same time, in the case of small archaeological objects it is difficult to evaluate the source from which the fragment of tested wood tissue was drawn.

Comparing the physical properties of archaeological wood to average values assumed for non-degraded fresh material may be unreliable from the point of view of wood decay evaluation. It is related to the lack of information on the properties of archaeological wood before its degradation. Therefore, such an evaluation, including the loss of wood substance calculated on the basis of changes in its basic density (Bilz and Macchioni, 2005; Grattan and Mathias, 1986), should always be treated as an approximation.

Most often a determination of the physical properties of archaeological wood under discussion is performed with the use of small, irregular samples. The mass and volume of the tested sample is determined by weighing the waterlogged wood in air and water, and weighing the oven-dried sample. The accuracy of such measurements is influenced by small amounts of air that still may remain in the wet wood, an excess of water on the sample surface, as well as by over-drying of the sample. Additionally, regarding the different properties of early and late wood – material that varies in macroscopic characteristics (e.g. width of annual increments) and non-homogeneity of the process of wood decay – the size of a sample will also influence the value obtained during the testing. In the case of small archaeological objects an evaluation of the degree of wood degradation is possible only with the use of non-destructive methods or by using very small samples. Due to the relatively high probability of a mistake resulting from weighing a wet sample and the increased density of sorbed water (Jensen and Gregory, 2006), an evaluation of wood decomposition on the basis of wood substance density determined on dry material with precise measurements of volume made with the use of a gas pycnometer seems worth considering.

The gas pycnometry method is based on Archimedes' principle of gas displacement. The sample volume is defined as the volume not occupied by gas in a calibrated chamber and determined by gas pressure measurements. Helium is the preferred displacement medium. It is a noble gas, it does not react with other substances and it is not adsorbed on the surface of solids at ambient temperature. Such properties of helium eliminate the problems connected with the formation of blow holes and dissolution of samples in liquids. In addition, helium molecules are small (0.255 nm), so they fill the tiniest pores of the sample and make it possible to precisely determine the sample volume. However, it should be noted that the closed pores that are inaccessible to helium are also included in the measured volume. This technique provides a fully automatic, high-precision and non-destructive measurements even on very small samples.

Wood substance density can be determined in water, some organic solvents or in gas (helium preferably). For fresh wood the values obtained in water are distinctly higher than the values obtained in helium or organic solvents (e.g. Christensen and Hergt, 1968). In spite of the differences in density of the main chemical components of cell walls (Beall, 1972) and differences in chemical composition of various wood species (Fengel and Grosser, 1975), in handbooks on wood science it is assumed that the density of fresh wood substance changes only within a narrow range and is independent of the type of tested wood. The research performed by Kellogg and Wangaard (1969) confirms this thesis to a great extent. Additionally, a strict dependence between wood substance density and the content of alpha-cellulose and crystallinity of cellulose has been found (Kellogg et al., 1975).

Changes in wood substance density predominantly result from the changes in percentage relationships between the main chemical components of the decomposing material. In the case of degraded archaeological wood in which the ratio of the content of polysaccharides to the content of lignin is decreased, wood substance density is lower than in non-degraded wood. This thesis was confirmed by Taniguchi et al. (1986a, 1986b). In turn, the influence of the loss of wood substance on the basic density of archaeological wood determined through various methods was tested by Passialis (1998).

In fresh wood, apart from the main chemical compounds and extractives (soluble in water or organic solvents), there is also a small content of mineral compounds. In wood of European species, the content of mineral compounds does not exceed 1% (Fengel and Grosser, 1975; Fengel and Wegener, 1989; Prosiński, 1984; Wagenführ and Schreiber, 1989). Due to the small amounts involved, their influence on wood substance density in sound wood was ignored. By contrast, in archaeological wood the ash content can increase by many times. It is particularly noticeable in material with a great degree of degradation in which the quantity of wood substance has decreased considerably. The higher participation of mineral compounds, which may even exceed 10% of the oven-dry mass of wood (Macchioni et al., 2012), results from the easy penetration of mineralized water into the wood. The density of salts in wood is considerably higher than the wood substance density. Therefore, following the increase in the degree of decay of carbohydrates and the increase in the content of mineral compounds, it is to be expected that the influence of mineral content on the density of wood substance and other physical properties measured for an evaluation of the degree of wood decomposition will be higher.

This research was aimed at making a comparison of the degree of decomposition of waterlogged archaeological wood evaluated on the basis of its basic density (and maximum moisture content) with an evaluation of wood degradation on the basis of wood substance density determined in water and helium. The research also included the influence of mineral compounds on selected physical properties and the estimated state of wood decomposition.

2. Material and methods

2.1. Wood

The research was done on 28 samples of waterlogged archaeological wood representing various hardwoods (oak, alder, ash, elm,