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Original article

Dimensional stability and hygroscopic properties of PEG treated irregularly degraded waterlogged Scots pine wood

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ABSTRACT

The study concerns the conservation problem of large scale elements of irregularly degraded archaeological wood being characterized by different susceptibility to agents responsible for wood consolidation and bulking. The conservation effectiveness was established for processes carried out with PEG solutions of different molecular weight with respect to dimensional stabilization, hygroscopic properties and the agent consumption. One of the investigated treatment options had concerned the application of PEG 2000, i.e. poorly studied variant of that type of consolidants. The analysis was performed for wooden elements from a Late Medieval road. The investigated artifacts were characterized by different anatomical structure and each of them included sapwood (SW) and heartwood (HW). Chemical, physical and sorption properties of SW and HW were first determined. A significant difference in the degree of degradation and the content of extractives in SW and HW was observed. The examined artifacts were then impregnated with five different PEG solutions. It was found that the highest anti-shrink efficiency (ASE) was obtained for one-stage PEG 2000 impregnation. The obtained data of sorption experiments showed that all applied impregnation options guaranteed safe exposure of wood in air relative humidity (RH) lower than 80%. Moreover, one-stage impregnation with PEG 2000 assured the lowest equilibrium moisture content (*EMC*) of wood, especially SW, at RH above 80%.

1. Introduction

Degradation of archaeological wood is a combination of processes which take place during three stages, i.e. utilization, deposition and finally awaiting for conservation. In the case of waterlogged wood, deposition conditions are usually near anaerobic ones, which makes the degradation limited. There are numerous examples of well-preserved objects reported in the literature [1,2]. Their good properties also result from the fact that they did not undergo degradation during utilization. Other definitely more unpredictable effects of degradation can be expected in wooden objects such as boats, roads, bridges or water supply systems which were exploited extensively and degraded before deposition [2–4]. Majority of wood artifacts is irregularly degraded in their cross section. The degradation process usually proceeds from outer to central zones of artifacts. In the case of pine wood sapwood is usually severely decayed while heartwood is well preserved. It results in an abrupt change in degradation at the interface between sapwood and heartwood. Therefore, such artifacts are characterized by irregular degradation in their cross section.

Scots pine (*Pinus sylvestris L.*) is the most common wood species found in archaeological sites in North-West Europe and Scandinavia. Due to its perfect technical properties and durability Scots pine wood has been widely used in building constructions. A typical application of the wood was to build roads in medieval towns [5,6]. Wooden road elements were subjected during their use to cyclic wetting and drying as well as mechanical loads. Such conditions caused alteration of chemical and mechanical properties of the wood [7,8].

The crucial features of waterlogged wood, i.e. resistance to biotic and abiotic factors, depend on hygroscopic properties, and it concerns both wood before and after impregnation processes. Hygroscopicity is a set of properties describing the wood-water system however, sorption isotherms, i.e. a relation between wood equilibrium moisture content (*EMC*) and air relative humidity (RH) at constant temperature, are the most common ones [9]. As far as

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fungal durability of waterlogged wood is often concerned, the *EMC* is the most important parameter. However, due to the phenomenon of sorption phenomenon the *EMC* should be determined separately for adsorption and desorption processes [2,10].

Hygroscopic properties of the waterlogged wood, including. *EMC* values, are usually determined before the final stage of the conservation treatment, i.e. drying (seasoning). In this case the initial desorption has to be considered as the moisture content (MC) of impregnated wood is above the fiber saturation point. Such hygroscopic characteristics are especially important for the proper selection of air parameters during drying (seasoning) of impregnated wood. However, the data cannot be used for predicting MC during exposition of artifacts. For that reason the hygroscopic properties have to be determined not only for the initial desorption (i.e. after impregnation and before seasoning) but also for adsorption and desorption of already impregnated and dried wood. Hygroscopic properties of treated and dried archaeological wood are rarely analyzed substantially, e.g. [11]. The study was performed for four levels of air *RH* only. However, it was possible to find differences in *EMC* values for different phases of sorption and for treated wood as well as for treated and dried material. Moreover, there was found a significant influence of pure consolidants and their retention on the hygroscopic properties of treated waterlogged archaeological wood [11].

The degradation of wood artifacts depends among other factors on the wood species and the dimensions of its cross section. Moreover, differences in anatomical structure, chemical composition and density of sapwood (SW) and heartwood (HW) cause inevitable variations in the degradation of wood. This is a one reason of for the risk of cracking of wood elements during its drying after impregnation. Therefore, a conservation process should account for the differences in wood structure, wood species and degree of degradation. Polyethylene glycol (PEG), the substance most often used for conservation of waterlogged wood, varies significantly in terms of hygroscopicity depending on its molecular weight [12–13]. Moreover, it was pointed out that PEG in impregnated wood is prone to different factors including heat, metal ions, salts, microbial and photo-chemical degradation [14]. It was also found that wood impregnation with PEG negatively influences mechanical properties of wood including the compressive and tensile strength [15] as well as creep properties leading to significant permanent wood deformation [16]. Catalytic oxidative degradation in PEG impregnated wood has also been observed [17].

In order to ensure durability of archaeological wood one has to select the appropriate conservation agent, apply proper parameters of wood impregnation and, ensure safety of exhibition of conserved wood artifacts. The proper selection of the conservation method is especially complicated for wood elements characterized by different properties of the material, i.e. anatomical and chemical structure, physical properties and deterioration. The different characteristics of the material together with the properties of the applied conservation agent might cause cracking of impregnated wood during the last stage of conservation (i.e. drying), or lead to a risk of fungal development when exposing wood at high air RH.

2. Research aim

The objective of the study was to determine hygroscopic properties and dimensional stability of adjacent zones of waterlogged archaeological wood characterized by different anatomical and chemical structure, irregular decay as well as applied low and high molecular weight PEG. The hygroscopic characteristics of the wood zones as obtained for (a) the final stage of the conservation treatment, i.e. drying (seasoning) and (b) subsequent adsorption and desorption phases, i.e. typical for exhibition will help to determine air parameters limiting wood cracking and fungal development, respectively.

3. Materials and methods

The research was conducted for waterlogged Scots pine wood obtained from the remains of a Late Medieval road (turn of the 14th and 15th century – Fig. 1). The wood was collected during the rescue excavations being conducted in Klasztorna Street in Grudziądz [13,18]. The investigated wooden elements were dated from the turn of the 14th and 15th century. Therefore, the material was explicitly identified as Scots pine since Austrian pine (*Pinus nigra Arn.*) characterized by practically identical macroscopic properties was introduced to Poland as early as in 1759. The investigated element was deposited at a depth of 0.5–0.8 m under a pavement of a contemporary road. The samples were drawn from an element with a length of 180 cm and a diameter of 30 cm.

The cross section of the investigated element and the cutting pattern of samples are presented in Fig. 2. A wood strip of dimensions of 35·70·700 mm in tangential, radial, and longitudinal direction, respectively, was first cut from the road element. The separation of sapwood and heartwood was based on the identification of the interface between the two zones. It was explicitly made due to significantly different color of sapwood and heartwood being a result of other anatomical structure, decay and water content. The strip consisted of equal parts of SW and HW. The strip was then cut into twin SW and HW elements in order to obtain two groups of 60 samples of SW or HW only. Each group consisted of 24 samples with dimensions of 30·30·10 mm, for tangential, radial and longitudinal directions, respectively used for the dimensional stability measurements as well as 36 samples with dimensions of 1.5·30·45 mm, for tangential, radial and longitudinal directions, respectively applied for sorption experiments. The obtained 120

Fig. 1. Lining elements of a medivel road in Grudziądz.

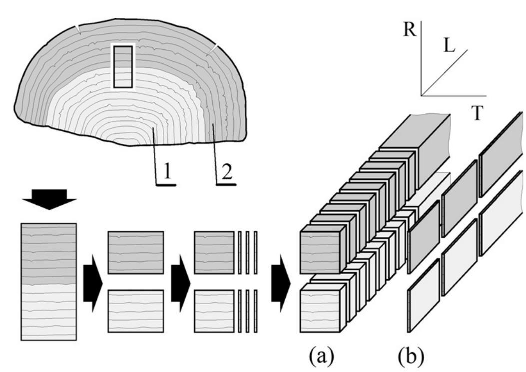

Fig. 2. Scheme of sampling: a: samples for shrinkage measurements; b: twin samples for sorption experiments; 1: heartwood (HW); 2: sapwood (SW).