International Biodeterioration & Biodegradation xxx (2017) 1–11

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

journal homepage: www.elsevier.com/locate/ibiod

The impact of 5 years' underwater exposure in the Baltic Sea (Puck Bay) on selected properties of English oak wood samples

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ARTICLE INFO

Article history:
Received 28 October 2016
Received in revised form
17 March 2017
Accepted 18 March 2017
Available online xxx

Keywords:
Marine environment
Biodegradation
Wood
Physical properties
Chemical composition
Fungi

ABSTRACT

In order to understand the influence of the underwater marine environment on changes in selected properties of contemporary wood, samples of oak wood were tested following several years of exposure at an underwater archaeological site (Puck Bay, Baltic Sea). The content of the major and minor components of the wood, as well as the total amount of minerals were determined. Selected physical properties were tested, as well as the strength and resistance of marine wood to rot caused by *Basidiomycetes* fungi. The study showed a decrease in the strength of the wood, changes in the chemical composition, and an increase in the quantity of mineral substances. In addition, a marked increase was found in the susceptibility of the tested wood to degradation by *Basidiomycetes*. These results indicate that the immersion of oak wood in the waters of Puck Bay caused significant changes in its physical, chemical and biological properties. Observations of changes occurring in contemporary wood can be useful in the monitoring of underwater archaeological sites.

1. Introduction

The protection of underwater archaeological sites has gained recently increasing importance. The main document setting forth the rules and procedures for the Protection of the Underwater Cultural Heritage is the UNESCO Convention from 2001 (UNESCO, 2001). According to this document, the protection of Underwater Cultural Heritage *in situ* is preferred for the conservation of waterlogged archaeological objects.

This convention describes in detail the conservation programme for long-time preservation, which should involve activities such as the preparation of documents for the archaeological site including a condition report, the monitoring system and an inventory (Rule 26), as well as underwater prospection (Rule 16) (Maarleveld et al., 2013).

The most important activities include the observation of changes in the environmental conditions within archaeological sites and the occurrence of threats to an underwater object, such as an attack by *Teredo navalis* - a shipworms wchich destroy the wooden wrecks (Björdal et al., 2011; MacIntosh et al., 2014; Charles et al., 2016). One of the methods for monitoring the degradation of archaeological wood, as well as a possible attack of marine-borer organisms, is the study of changes in modern wood submerged around archaeological sites (Pomian et al., 2010; Fojutowski et al., 2011, 2014). The test of contemporary wood samples after several years of exposure at underwater archaeological sites may help to understand the effect of the underwater marine environment on changes in the properties of wood.

To evaluate changes in the properties of contemporary wood under the influence of the underwater environment of the Baltic Sea, two different underwater archaeological sites were selected (Orłowo site and Puck Bay site). These sites were chosen within the international MACHU project (Managing Cultural Heritage Underwater) dedicated to the protection of underwater cultural heritage.

The Orłowo archaeological site located in the Gdansk Bay is the place of resting on the sandy bottom at depth of 14 m, the wreck of Solen, a Swedish warship (sank in 1627) (Pomian, 2009; Fojutowski et al., 2014).

The Puck Bay site is placed in the surrounding of the remains of

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http://dx.doi.org/10.1016/j.ibiod.2017.03.016
0964-8305/

the medieval port in Puck. The relic of port discovered in 1977, is example of a unique and well-preserved port complex on the Polish coast. The site is located at the mouth of the river Płutnica, about 150 m from the shoreline and covering an area of over 12 ha of the bottom of the western part of Puck Bay. The water depth varies from 1.5 to 2.5 m. The main part of the archaeological site comprises wooden structures, fascine, mounds of stone and earth (Stępień, 1987). The oldest wooden piers date back to the first half of the tenth century (Litwin and Pomian, 2006).

A detailed description of the Orłowo and Puck Bay sites, which includes hydrogeological information, is presented in documents from the National Maritime Museum (NMM), on the webpage www.machuproject.eu and in the project reports (MACHU Reports, 2008, 2009, 2010).

In the previous paper the authors reported the results of experiment concerning submergence of the oak wood samples for two years in the Baltic Sea at a depth of about 14 m near the wreck of the Swedish warship Solen (Orłowo site) (Fojutowski et al., 2014).

The aim of the presented research was to determine the changes in the physical, chemical and biological properties of oak wood samples caused by the submergence of the samples under different conditions in Puck Bay (the Baltic Sea) at the depth of 2 m for five years.

2. Materials and methods

2.1. Materials

The material studied was sound Englih oak heartwood (*Quercus robur* L.). The samples for the experiment were prepared from strips measuring 250 mm × 50 mm × 10 mm. One oak strip was cut to obtain 4 samples (little beams) with the dimensions 250 mm (L) × 10 mm (T) × 10 mm (R) (L – length, T – tangential, R – radial). The third beam, in turn, was used as a control while the other three beams were submerged in sea water. Forty-five beams were attached to one rope. Eight ropes were prepared for different periods of submergence from 6 month to several years and placed underwater (Figs. 1 and 2) at both archaeological sites (Pomian et al., 2010; Fojutowski et al., 2011, 2014).

2.2. Methods

After the exposure period, one test rope was removed from the seawater at the Puck location and immediately delivered to the Wood Technology Institute in a wet state. The samples of wood (beams) taken from the underwater archaeological site, after preliminary examination and the execution of photographic documentation, were cleaned, dried, air-conditioned and prepared for analysis of the physical, chemical and biological properties.

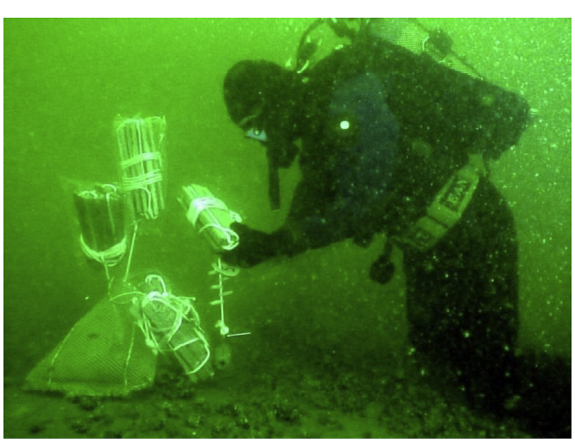

Fig. 1. Diver mounting ropes with the samples at underwater archaeological site (Photo: Tomasz Bednarz).

The following properties of the oak wood were determined and analysed according to the standards and methods whose principles were described in detail in a previous paper (Fojutowski et al., 2014).

2.2.1. Organoleptic assessment

Observation of the samples were conducted in order to find marine organisms on the surface of the wood (visible to the naked eye), a change in the colour of the wood, and the condition of the surface and edges of the test samples. After observation, biofilm and marine organisms were removed from the surface of the test samples using tap water. Following this, the samples were weighed in a wet state and dried under laboratory conditions to constant weight. The general view, condition and mass of the test samples were compared to the control samples.

2.2.2. Physical and mechanical properties

The standardized testing methods given in parentheses were used to examine wood density (PN-77/D-04101), loss of mass by oven-dry method (PN-EN 13183-1), the equilibrium moisture content under standard conditions 20°C/65%RH (PN-EN 13831-1), bending strength and modulus of elasticity at three-point bending test (PN-77/D-04103 and PN-63/D-04117) and parallel to grain compression strength (PN-79/D-04102).

For the calculations, formulas described by Fojutowski et al. (2014) were used. The wood samples for the strength tests were at a state of equilibrium moisture content under conditions 20°C/65% RH. The statistical significance of the noted changes was estimated according to the standard method (PN-N-01052-03) at a confidence level of $\alpha = 0.05$.

2.2.3. Chemical composition of the wood

From each test rope, 10 samples (small beams) which had been submerged in the waters of the Baltic Sea were tested to determine the chemical composition of the wood. Twin control samples (10 samples), which had not been submerged, were tested to compare their chemical properties. The tested beams in an air-dry state (with a moisture content of approx. 10%) were cut into 3-cm segments, which were ground using a knife mill, and the resulting sawdust (particles) sieved into fractions of a grain size of 0.25–0.5 and 0.5–1.0 mm. The moisture content was determined using the oven-weight method at 103 ± 2 °C.

The chemical analysis of the oak wood included the quantity examinations of extractives, substances soluble in water (cold and hot) and in 1% of NaOH, Seifert cellulose, Klason lignin, pentosans, mineral substances and pH according to standard methods given below.

The content of extractives was determined in Soxhlet apparatus with 95% ethanol (TAPPI standard T204). The content of substances soluble in cold and hot water was analysed by TAPPI T207 method, and substances soluble in 1% NaOH aqueous solution by TAPPI T212 method. The amount of Seifert cellulose and Klason lignin in tested wood were examined by PN-92/P-50092 and TAPPI T222 standards respectively. In quantitative analysis of pentosans, were used the Tollens method with phloroglucinol (Prosiński, 1984; TAPPI T223). The content of mineral substances (ash) was examined (combustion at 575 ± 25 °C) according to Prosiński (1984) and TAPPI T211 standard. The value of pH (grain size 0.25–0.5 mm) was analysed according to the Gray method (Gray, 1958; Fojutowski et al., 2014).

The quantity of the elements typical of sea water (Pawuła, 1997)