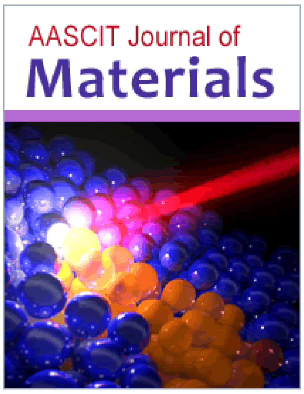
AASCIT Journal of Materials
2015; 1(2): 31-34
Published online July 10, 2015 (http://www.aascit.org/journal/materials)

American Association for Science and Technology



Keywords
Timber Structures,
Anoxic Conditions,
Scots Pine,
Bacterial Degradation

Received: April 13, 2015
Revised: June 27, 2015
Accepted: June 28, 2015

Bacterial Decay of Wooden River Moorings After 75 Years in Service

M. Kisternaya[1], V. Kozlov[2]

[1]Kizhi Open-Air Museum, Petrozavodsk, Karelia, Russia
[2]Forest Research Institute, Russian Academy of Sciences, Petrozavodsk, Karelia, Russia

Email address
kisternaya@kizhi.karelia.ru (M. Kisternaya), vkozlov@krc.karelia.ru (V. Kozlov)

Citation
M. Kisternaya, V. Kozlov. Bacterial Decay of Wooden River Moorings After 75 Years in Service. *AASCIT Journal of Materials.* Vol. 1, No. 2, 2015, pp. 31-34.

Abstract
This study provides some information about the degree of bacterial degradation in pine waterside structures that have been in service for 75 years in running fresh water. It was revealed that 71% of pine heartwood samples were damaged to a weak or moderate degree and 5% were degraded severely and, therefore bacterial degradation of wood in anoxic conditions was underestimated before. The results proved the idea that water movement in the waterlogged structures is a key factor that stimulates bacterial wood degradation. The obtained patterns of bacterial degradation throughout the whole length of a mooring beam showed that head beams can be regarded as a representative of the whole element. It was concluded that the mooring beams under consideration can serve for at least 50 years more.

1. Introduction

Longevity of timber structures: dwelling houses, buildings for public worship and waterside structures is a burning problem for civil engineers, conservators and private owners especially in the northern parts of Europe where wood-working traditions have been strong since prehistoric times. Aboveground wood as a biological material is exposed to deterioration caused by fungi and insects. It was revealed that in the Northern Europe brown rot fungi are the main destructors of wooden structures (Viitanen, Ri1tchkoff, 1991; Mattsson, 2010). Insects are secondary destructors whereas their danger is also severe (Polevoj, Kozlov, 2013).

For a long time it was believed that the use of timber under very-low-oxygen conditions (f. ex. in fresh or marine water or in water-saturated soil) could protect wood from biological degradation for centuries or even millennia. Wood has been widely used for pile foundations until the World War II when the large-scale introduction of concrete foundation piles has began. Nowadays in the Netherlands, there are more than 25 million wooden foundation piles supporting buildings (Klaassen, 2005). Numerous historic structures standing on wooden pile foundations in Saint-Petersburg, Archangelsk, Leptzig, Hamburg and Venice prove the idea that those foundations can serve for centuries. There are records of wooden remains over a long period of more then 2000 years. Whereas even 100 years piling constructions, which were always underneath the groundwater table could be severely degraded

Only at the end of the XX century it was found that degradation of wood under (almost) anoxic conditions, was caused by bacteria. Nilsson and his co-workers described general patterns of bacterial wood degradation and isolated these bacteria (Daniel & Nilsson, 1986, 1997; Blanchette et al., 1990; Singh et al., 1990; Bjordal et al., 1999).

Large-scale EU project “Preserving cultural heritage by preventing bacterial decay of wood in foundation piles and archaeological sites" (EVK4-2001-00043, 2002–2005) obtained basic knowledge about the impact of bacterial degradation on wooden foundations and archaeological wooden remains.

The research enabled classification of different degrees of bacterial wood degradation as well as the isolation and identification of wood attacking bacteria (Klaassen, 2005). It became clear that all wooden foundation piles that have been in service for about 100 years and that are situated under the groundwater level show bacterial decay at least in their outermost layer. At the same time the speed of attack and, therefore the degree of bacterial degradation to a large extent depends on the conditions and wood specie (Klaassen, 2007; Klaassen, 2012).

The data on the longevity of wooden mooring structures is very limited (Gavronski, 2002; Landy et.al., 2007). Moorings are mainly built from softwoods which were found to be more succeptible for the degradation beneath the groundwater level and in the 1970s, pine was even excluded as a wood used for foundations (Buiten, 1997). Comparing with wooden piles mooring structures are mainly built of squared beams which means that the most succeptible for bacterial degradation sapwood is removed. At the same time they are exposed to river water movement, which is identified as a key factor that stimulates bacterial wood degradation (Klaassen, 2007). To predict the lifetime of a wooden moorings the estimation of the velocity of the decay as well as knowledge on the active state is needed.

In this paper, the degradation of pine wood used for river mooring structures which have been in service in anoxic fresh water conditions for about 75 years has been studied.

2. Material and Methods

2.1. Materials

Samples originate from wooden river mooring built in 1938-39. Piles (Ø28-30 cm) extended deep into the soil layer serve as a foundation for a concrete mooring plate. The waterside structure on the border between soil and water is made of vertical squared wooden beams.

2.2. Work Procedure

Figure 1. Cores taken at the beam head (right), in its middle part (central) and its foot, near the ground (left).

As in all samples the bacterial decay increases from the pith to the bark side, 49 samples were taken from this waterside structure (from the side facing water) in a radial direction from the outside toward the centre of the beam with a hand-driven increment borer (Ø5 mm) (Fig. 1).

Cores were taken from beams below the beam head, in its middle part and at its foot. Each core was sealed, together with some river water, in a plastic tube and sent to the laboratory where wood anatomical structure and degradation patterns were studied.

2.3. Tests

Blocks (5 mm x 5 mm x 10 mm) were cut from the increment cores. Thin sections (20 µm) were prepared from the cross section. When cases of heavy degradation occurred, the thickness of the thin sections was increased to 30 µm. Wood was stained with Picrine Aniline Blue for 1-3 min. Then wood specie was determined by microsopical features (Panshin et.al., 1980).

All sections were imbedded in glycerine for temporary storage. The wood structure and the pattern of degradation were studied with a light microscope Leica DFC 295 using final magnifications of 100, 200 and 400.

Degree of degradation due to erosion bacteria was estimated by 5-grade scale proposed by R. Klaassen (2008) as absent (0), weak (1), moderate (2), severe (3) and totally desintegrated (4).

3. Results and Discussion

The analysis shows that all beams are made of Scots pine (*Pinus sylvestris* L.) wood. The samples preserved the tracheid cell wall structure. The color of samples varies from light-yellow to light brown and grey. Giphae of basidomicets and soft rot fungi are not revealed, bacteria are the main destroying agents of wood under consideration.

Figure 2 illustrates the observed degree of bacterial degradation of the samples. Twenty four percent of them have no damages in cell walls.

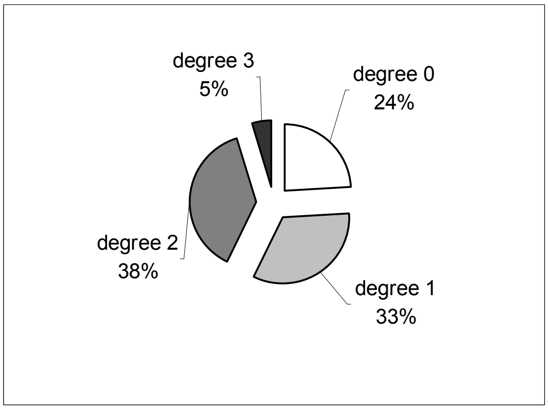


Figure 2. Degree of the bacterial degradation for the beams.

Degraded ray cell walls and parts of isolated late wood tracheids are observed in longitudinal sections for thirty three percent of samples. For these samples in some early wood tracheids cell wall with small eroded grooves ("V" shaped notches) are detected and the degree of destruction is classified as a weak one (1st degree).

Unexpectedly large amount of samples – thirty eight percent are damaged moderately (2nd degree according to R. Klaassen, 2008). Isolated degraded cells are preserved in a matrix of sound cells with a higher intensity round the rays. Early wood tracheids have grooved-like eroded areas. Whereas the border between sound and degraded cell-wall parts is sharp.

Only five percent of samples are severely damaged (see Fig. 2). In these samples isolated sound cells are observed in a matrix of degraded cells, almost all tracheid cell walls are fully eroded and filled with amorphous residue material. Early tracheid cell walls are fully eroded in grooved-like pattern following more or less the micro-fibrilaire angle.

Totally disintegrated samples (degree 4 according to R. Klaassen) were not revealed.

The most prominent damages are located close to the rays because at the initial stages of decay the infection is being restricted to those cells that are directly involved in the water-transport pathways like rays in pine.

The piles are made of squared beams and, therefore there is no “protective” sapwood layer. Whereas the research revealed a moderate degradation rate for a pine heartwood which was suspected to be more durable to bacterial wood decay (Gawronski, 2002). Weak and moderate degradation rates for mooring wooden beams is revealed after 75 years in service. Whereas in pine piles heartwood remains intact when the sapwood is severely damaged after 100 years in service (Klaassen, 2009). It is due to structure boundaries in wood which reduce the decay velocity (Klaassen, 2007).

In the tested samples heartwood parts at the border with water are damaged to a greater degree. The depth of damage is different and related to the degree of degradation (Table). Severely damaged samples have deeper penetration of bacteria.

Table. *Depth of degradation for samples with different degree of degradation.*

Degree of degradation	Depth of degradation, mm
Weak (1)	8±3
Moderate (2),	9±4
Severe (3)	11±3

The estimated velocity of bacterial decay for samples with a weak degree of degradation is 0,11 mm/year and 0,15 mm/year for severely damaged samples. The difference in velocity between weak and severe is approximately 36% as blockage of the wood structure is to be expected in the degraded area. The results are in agreement with data obtained by R. Klaassen, proved that over a period of 100 years, in pine, the minimum velocity of bacterial decay can vary from 0 mm/year to 0.23 mm/year (Klaassen, 2007; Klaassen, 2014).

The degradation rate can be explained by the local conditions (high water-flow rate, water chemical composition, temperature etc.) determine velocity of bacterial degradation. Several groups of bacteria working in consortia which cause the bacterial degradation of waterlogged wood need to be transported inside the wood by an additional force or forces (Nilsson and Bjordal, 2007; Klaassen, 2007). That’s why water flow rate is the dominant factor in the bacterial degradation.

Prediction of mooring elements longevity is of great importance for the safety requirements. Wood-destroying bacteria belong to the CFB (*Cytophaga-Flavobacterium-Bacteroides*) complex penetrate deeply in wood degrading cellulose and hemicellulose (Landy et.al., 2007). Whereas the preserved untouched tracheid cell wells provide strength properties of wood.

It is known that under optimal conditions weak bacterial decay velocity for pine is estimated on 0,3 – 0,7 mm/year whereas the severe decay velocity is 0,7 – 1,0 mm/year (Klaassen, 2007). Therefore the service life of wooden moorings in stable hydrological conditions can be secured for 50 years-long time span at least.

It is known that an active bacterial decay can be recognized by the clear differentiation between the different degrees of degradation. The degradation can be regarded as not active when the depth of weak and severe decay is more or less equal (Klaassen, 2007).

The obtained data show that the degradation of wooden piles slowly goes on therefore permanent monitoring of their condition is required.

The beam heads are damaged to a greater degree comparing with foots and middle parts (Fig. 3). Severely damaged samples are also taken in the beam head zones. It can be explained by the fact that the river water level changes and those parts of the mooring could stay in dry conditions for some period of time. Probably oxygen, which could be available in this case, can be considered as a trigger for bacterial degradation. The obtained results are inconsistent with the data obtained by R. Klaassen (2008) for wooden piles which were degraded by bacteria over their full length with no observable gradient across pile length. However, local higher degradation intensities across the pile length can be explained by lower water flow velocities close to the bottom of the river (Schmidt, 1980, Klaassen, 2005).

The results presented in this paper suggest that the status of the beam head, in terms of degradation assessment, can be regarded as the representative of the whole element. This is important for regular inventories.

4. Conclusions

The research revealed bacterial degradation for 76% of pine samples after 75 years in service in fresh water anaerobic conditions. The majority of samples are damaged in a weak or moderate degree. The most prominent damages are located close to the rays because they are directly involved in the water-transport pathways.

It was found that for beams the degree of bacterial degradation a little bit higher then for a round timber because the wood structure boundaries (i.e. sapwood/heartwood barrier) are absent.

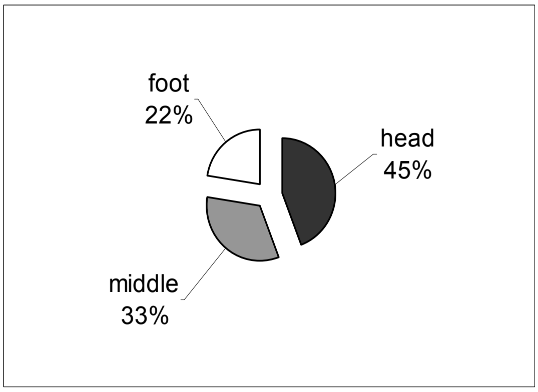


Figure 3. *Location of revealed damages in the head, middle and foot parts of the beams.*

The hypothesis that local hydrology and, namely high water-flow rate can be responsible for the degradation rate was proved.

The study made on the pattern of bacterial degradation throughout the whole length of a mooring beam showed that head beams are damaged to a greater degree comparing with the rest of the beam. Its condition can be regarded as the representative of the whole element.

The obtained data enabled forecasting of 50-years long service life for the mooring beams under consideration.

The data on condition of mooring structural elements help to understand the process of bacterial degradation and estimate its severity.

Acknowledgements

The research is supported with the Russian Foundation for Basic Research (Grant # 15-08-01893).

References

[1] Bjordal, C.G. & Nilsson, T. & Daniel, G.E. 1999. Microbial decay of waterlogged archaeological wood found in Sweden. Applicable to archaeology and conservation. *International Biodeterioration & Biodegradation* 43, 63–71.

[2] Blanchette, R.A. & Nilsson, T. & Daniel, G. & Abad, A. 1990. Biological degradation of wood. In: Rowell, R.M., Barbour, R.J. (Eds.), *Archaeological Wood: Properties Chemistry, and Preservation*.

[3] Buiten, H. 1997. Houten heipalen. In: *Houtdocumentatie* 18.

[4] Daniel, G. & Nilsson, T. 1986. Ultrastructural observations on wood degrading erosion bacteria. IRG/WP/1283.

[5] Daniel, G. & Nilsson, T. 1997. Developments in the study of soft rot and bacterial decay. In: Bruce, A. Palfreymans (Eds.), *Forest Products Biotechnology*. Taylor & Francis Publ., London.

[6] Gawronski, J. 2002. Archeologie op Oostenburg, de Amsterdamse stadsuitleg en het martitieme cultuurlandschap. In: Gawronski, J. & Schmidt, F. & Van Thoor, M. Th., *Amsterdam Monumenten & Archeologie 1. Uitgeverij Bas Lubberhuizen*.

[7] Klaassen, R.K.W.M. (Ed.) 2005. Final Report of EU Project BACPOLES, Preserving Cultural Heritage by Preventing Bacterial Decay of Wood in Foundation Piles and Archaeological Sites EU number: EVK4-CT-2001-00043.

[8] Klaassen R.K.W.M. 2007. Velocity of bacterial decay in wooden foundation piles. Proceeding ICOM. Amsterdam

[9] Klaassen R.K.W.M. 2008. Bacterial decay in wooden foundation piles—Patterns and causes: A study of historical pile foundations in the Netherlands. International Biodeterioration & Biodegradation. 61: 45–60

[10] Klaassen, R.K.W.M., Overeem, B.S., 2012. Factors that influence the speed of bacterial wood degradation. Journal of Cultural Heritage, 13 (3): 129-134

[11] Klaassen R.K.W.M. 2014. Speed of bacterial decay in waterlogged wood in soil and open water International Biodeterioration & Biodegradation 86 (2014) 129-135

[12] Kretschmar, E.I. & Gelbrich, J. & Militz, H. & Lamersdorf, N. 2007. Studying bacterial wood decay under low oxygen conditions—results of microcosm experiments. International Biodeterioration & Biodegradation, doi:10.1016/j.ibiod.2007.07.004.

[13] Landy, E.T. & Mitchell, J.I. & Hotchkiss, S. & Eaton, R.A. 2007. Bacterial Diversity Associated with Archaeological Waterlogged Wood: Ribosomal RNA Clone Libraries and Denaturing Gradient Gel Electrophoresis (DGGE). *International Biodeterioration & Biodegradation,* doi:10.1016/j.ibiod.2007.07.007.

[14] Mattsson J. 2010. Råtesopp i bygninger. Farekomst, påvisning vurdering og utbedring. Mycoteam. Oslo. 127 p.

[15] Nilsson, T. & Bjordal, C. 2007. The use of kapok fibres for enrichment cultures of lignocellulose-degrading bacteria. *International Biodeterioration & Biodegradation*, doi:10.1016/j.ibiod.2007.06.009.

[16] Panshin, A.J. & De Zeeuw, C. 1980. *Textbook of Wood Technology, Structure, Identification, Properties, and Uses of the Commercial Woods of the United States and Canada*, fourth ed. McGraw-Hill Publishing Company, New York.

[17] Polevoj A., Kozlov V. 2012. Insects damaging wooden constructions in Karelia / Fungi and beetles in historic timber structures in Northern Europe. Proceedings of the workshop. May, 29th – June, 1st 2012, Petrozavodsk. Petrozavodsk. P. 45-49

[18] Singh, A.P. & Nilsson, T. & Daniel, G.F. 1990. Bacterial attack of Pinus sylvestris wood under near anaerobic conditions. *Journal of the Institute of Wood Science*, 11: 237–244

[19] Schmidt, O. 1980. Laboratory experiments on the bacterial activity towards the woody cell wall. In: Oxley, T.A. & Allsopp, D. & Bekker, G. (Eds.), *Biodeterioration, Proceedings of the Fourth International Symposium Berlin*. Pitman Publs. Ltd., London and the Biodeterioration Society.

[20] Viitanen H., Ritschkoff A.C. 1991. Brown rot decay in wooden constructions. Effects of temperature, humidity and moisture. Swedish university of agricultural sciences deparment of forest products, report N 222,. Uppsala, 55 p.