FORESTRY

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Gavrilov T.A.[1] *, Stankevich T.B.[2]
[1] ORCID: 0000-0003-3671-0971;
[2] ORCID: 0000-0001-8582-1745;

[1, 2] Petrozavodsk State University, Petrozavodsk, Russia

* Correspodning author (gtimmo[at]mail.ru)

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THE INFLUENCE OF NATURAL AND CLIMATIC FACTORS ON THE WOOD BIODESTRUCTION PROCESS

Research article

Abstract

Monuments of wooden architecture undergo biodegradation over time. It reduces their service life, causes large material losses and leads to their partial or complete loss as objects of cultural heritage. Wood-destroying fungi play a leading role in the biodegradation of wood. Traditional methods of protecting wood from wood-destroying fungi, such as constructive, antiseptic and mechanical, are of little use or ineffective for protecting monuments of wooden architecture, since they have a number of features as cultural heritage objects. At the same time the intensity and nature of wood biodegradation and the change in its physical and mechanical properties directly depend on the natural and climatic factors of the environment. The issue of studying the regularities of natural and climatic factors influence on the process of wood biodegradation is particularly relevant in the development of methods for protecting it from wood-destroying fungi. This is the purpose of this study. According to the results of the study, it was revealed that wood-destroying fungi ruin the cell walls of wood, which leads to a decrease in its physical and mechanical characteristics. The intensity and nature of biodegradation depend on the temperature and humidity of the air, as well as the moisture content of the wood. At a temperature of 18–36 °C, an air humidity of 75–100 %, and a wood moisture content of 23–70 %, the process of biodegradation proceeds most intensively.

Keywords: timber, wood-destroying fungi rotting, air temperature, timber moisture content, timber strength.

Гаврилов Т.А.[1] *, Станкевич Т.Б.[2]
[1] ORCID: 0000-0003-3671-0971;
[2] ORCID: 0000-0001-8582-1745;

[1, 2] Петрозаводский государственный университет, Петрозаводск, Россия

* Корреспондирующий автор (gtimmo[at]mail.ru)

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ВЛИЯНИЕ ПРИРОДНО-КЛИМАТИЧЕСКИХ ФАКТОРОВ НА ПРОЦЕСС БИОРАЗРУШЕНИЯ ДРЕВЕСИНЫ

Научная статья

Аннотация

Памятники деревянной архитектуры с течением времени подвергается биоразрушению, что сокращает срок их эксплуатации, вызывает большие материальные потери и приводит к их частичной или полной утрате, как объектов культурного наследия. Ведущую роль в биоразрушении древесины играют дереворазрушающие грибы. Традиционные методы защиты древесины от дереворазрушающих грибов, такие как конструктивные, антисептические и механические, малоприменимы или неэффективны для защиты памятников деревянной архитектуры, ввиду их ряда особенностей, как объектов культурного наследия. При этом известно, что интенсивность и характер биоразрушения древесины и изменение ее физико-механических свойств напрямую зависят от природно-климатических факторов окружающей среды. В связи с чем, вопрос изучение закономерностей влияния природно-климатических факторов на процесс биоразрушения древесины является особо актуальным при разработке методов ее защиты от дереворазрушающих грибов, что и является целью данного исследования. По результатам исследования выявлено, что дереворазрушающие грибы разрушают клеточные стенки древесины, что ведет к снижению ее физико-механических характеристик. Интенсивность и характер биоразрушения зависят от температуры и влажности воздуха, а также влажности древесины. При температуре 18–36 °С, влажности воздуха 75–100 % и влажности древесины 23–70 % процесс биоразрушения протекает наиболее интенсивно.

Ключевые слова: древесина, дереворазрушающие грибы, гниение, температура воздуха, влажность древесины, прочность древесины.

1. Introduction

Wood is a valuable, renewable and the most affordable building material, the characteristic properties of which are: high strength, low thermal conductivity, low volume weight, high machinability, good nailability. At the same time, the cost of wood is relatively lower than that of other building materials. In this connection, wood is widely used in the construction of buildings and structures.

2. Results

The condition and durability of wooden structures directly depend on the natural and climatic conditions in which they are located. Thus, if the correct temperature and humidity regime is not observed, the wooden structures and buildingsare known to undergo biodestruction, which is the most common cause of the collapse of both relatively new and historical structures (including monuments of wooden architecture) [1]. Wood-destroying fungi play the leading role in the biodegradation of wood [2], [3], [4]. The intensity of biodegradation depends not so much on the type of wood-destroying fungi, but on the temperature and humidity conditions in which certain buildings and structures are located [5]. The main cause of destruction is a change in the physical and mechanical properties of wood under the action of wood-destroying fungi [6], [7]. In this connection, one of the approaches to the study of the biodegradation process is theexamination of changes in the physical and mechanical properties of wood in the process of its biodestruction.

Wood biodegradation in building structures significantly reduces their service life and causes large material losses. For example, 20 % of the total amount of commercial timber harvested in Russia is known to be used only to make up for its losses from biodegradation caused by the activity of wood-destroying fungi [8].

No less important than material losses are the problem of partial or complete loss of cultural heritage objects in the process of biodegradation of wooden structures of architectural monuments. Monuments of wooden architecture keeping the history, traditions and life of people of previous generations, are a reflection and documentary evidence of the past, information about which must be preserved and passed on to the future generations. The preservation of cultural heritage sites is an important task and allows maintaining the connectionbetween the past, present and future.

To protect the wooden buildings and structures, constructive, antiseptic and mechanical measures are used. Constructive measures are aimed at preventing conditions favorable for the development of the wood decomposition process by wood-destroying fungi. For example, all wooden buildings and structures must be designed so that they could not receive moisture from foundations; ventilation of buildings and structures should ensure the removal of moisture from floors, ceilings, etc. Antiseptic measures measures are aimed at the chemical destruction of wood-destroying fungi on the surface and in the thickness of wooden structures and buildings by impregnating and smearing them with antiseptics. Mechanical measures are aimed at removing sections of wooden structures affected by wood-destroying fungi and replacing them.

The complex use of the described measures makes it possible to provide sufficiently reliable protection of wooden buildings and structures from biodegradation. But this whole complex of measures is applicable only for buildings and structures that are not related to the monuments of wooden architecture. Thus, constructive measures are not possible due to the fact that the monuments of wooden architecture already have a certain design and making changes to them will lead to the loss of the status of a cultural heritage site. Antiseptic measures negatively affect the physical and mechanical properties of the structures of wooden architecture monuments, and also have a number of other disadvantages. So, for example, in [2], in the course of studying the state of wooden structures of the Church of the Transfiguration (1714, Kizhi Island, Republic of Karelia), it was revealed that deep chemical conservation led to violations of the integrity of wood, did not provide reliable protection against wood-destroying fungi and created unfavorable environmental conditions. Mechanical measures are very limited, because when replacing more than 42 % of the original structures and elements of wooden architecture monuments, they lose the status of a cultural heritage object.

Due to the inapplicability or inefficiency of existing measures to protect the structures of wooden architecture monuments, there is a need to develop new modern measures that can effectively protect the structures of wooden architecture monuments from biodegradation, while not exposing them to the risk of losing the status of an object of cultural heritage. Such activities should be based on the scientific foundations obtained in the course of studying the regularities of the influence of natural and climatic factors on the process of wood biodegradation, since the intensity and nature of the biodegradation of wood and the change in its physical and mechanical properties are known to depend directly on the natural and climatic factors of the environment [5].

In this connection, the purpose of this study is to examine the regularities of the influence of natural and climatic factors on the wood biodegradation process.

The state of wooden structures of architectural monuments can be characterized by the degree of their damage by wood-destroying fungi.

Wood-destroying fungi ruining wooden buildings and structures are known as house fungi. In a broad sense, this name refers to all fungi that are found on the wooden buildings and structures. However, only *Merulius lacrymans* (*Serpula lacrymans*), *Poria vaporaria*, *Coniophora cerebella*, and *Paxillus acheruntius* are of practical interest because they cause the strongest and most rapid destruction of wood [9]. So, for example, in [10] it is indicated that among the studied species of wood-destroying fungi, the membranous house fungus *Coniophora cerebella* (during the study it almost completely destroyed a wood sample) and the real house fungus *Merulius lacrymans* (hit about 50 % of the sample volume) exhibited the maximum ability for wood biocorrosion.

An important feature of wood-destroying fungi, as lower plant organisms, is that they are not photosynthetic [11]. Their cells lack chlorophyll, which is found in other plant organisms, therefore they cannot independently create the organic substances they need for nutrition and are forced to obtain them either from living plants, or from dead parts of plants and decaying organic substances.

Having penetrated the wood of buildings and structures and found favorable conditions there, wood-destroying fungi begin to grow in it, feeding on its nutrients. For their nutrition, wood-destroying fungi use two types of nutrients in wood:

1) the contents of the cells,

2) the composition of the cell walls. The content of wood cells is very different: in addition to protoplasm (protein substances), there are sugar, oils, starch, tannins and dyes, resins, gums, minerals in soluble form, etc.

The cell walls of wood consist mainly of cellulose and wood substances (including lignin). Cellulose is included in the cell walls as a fibrous framework and provides the strength and flexibility of wood [12]. Some wood-destroying fungi consume only the contents of the cells, while others consume both the contents of the cells and the cell walls. To make nutrients soluble, wood-destroying fungi secrete various enzymes that are contained in their hyphae and fruiting bodies.

Biodegradation of wood under the action of wood-destroying fungi occurs gradually and is a process of decomposition of the constituent wood parts, leading to its destruction. As wood decomposes, carbon dioxide and water are released.

It is customary to distinguish between two stages of decomposition: initial and final [5]. In the initial stage, decomposition is expressed in the fact that wood begins to change its normal properties: its color changes, strength decreases. In the final stage, the wood becomes dark brown, easily breaks up into separate prisms or stratifies along annual rings with the formation of various depressions and efflorescences. The strength is almost lost, the wood easily crumbles into small fibers or is rubbed between the fingers into powder.

Depending on the nature and appearance of decomposition in the final stage, two types of decomposition have been established [12]: destructive, caused by dangerous wood destroyers – cellulose-destroying fungi (at the same time, the wood becomes dark brown, a network of cracks appears in it and it breaks up into separate prismatic pieces; the amount of cellulose sharply decreases, and lignin increases; in the absence of cellulose, wood becomes brittle, easily breaks and crumbles, greatly reduces in volume and loses weight, often cracks prismatically [13]); corrosive, caused by less dangerous fungi – lignin-destroying fungi (in this case, voids visible to the naked eye in the form of "lentils", pits are formed in the wood; then efflorescence or white spots of cellulose appear; the wood retains its viscosity; the amount of lignin decreases, and cellulose almost does not change; the wood becomes light-colored, soft and fibrous, loses weight, but its volume does not decrease). There is also a mixed type of decomposition - corrosion-destructive, when the enzymatic apparatus of fungi is equally directed to the destruction of both cellulose and lignin (in this case, motley (net) rot is formed) [11]. It should be noted that lignin-destroying fungi alone, and cellulose-destroying fungi together with them, can completely decompose wood without the participation of other organisms [14], [15].

In the process of wood decomposition, morphological and structural transformations occur in it, leading to a change in its physical and mechanical properties (density, hardness, strength, rigidity, etc. decrease) [9], [16], [17]. They change especially strongly at the last stage of wood decay. Thus, in [9] it is noted that the hardness (according to the Brinell-Jank method) of aspen wood decomposed by the fungus *Fomes igniarius* and pine wood decomposed by the fungus *Trametes pini* becomes 17 times less, and oak wood decomposed by the fungus *Polyporus sulphureus* 35 times less (compared to healthy wood). In [17], it is noted that the compressive strength along and across the fibers of partially destroyed wood of the Anglican Church crown becomes 3,84 and 5,70 times lower, and the flexural strength along the fibers is 4,46 times lower.

The intensity and nature of the biodegradation of wooden buildings and structures and the change in their physical and mechanical properties directly depend on the natural and climatic factors of the environment. It is known [9] that the germination of spores and the development of mycelium of wood-destroying fungi is possible only under certain natural and climatic conditions. The most significant of which are: temperature and humidity, as well as wood moisture. In addition, the growth of wood-destroying fungi is influenced by the amount of oxygen and light, the acidity of the environment, and the presence of poisonous and harmful substances in the wood.

Wood-destroying fungi can grow only in certain ranges of air temperature. There are minimum, maximum and optimum temperatures. These temperatures are different for various wood-destroying fungi, and they are also different for the growth of different parts of the same wood-destroying fungus, such as for spore germination, mycelium growth, and fruiting. It should be noted that the indicated minimum, maximum and optimum temperatures may vary depending on the environment in which the wood-destroying fungus develops. Most wood-destroying fungi can develop in the temperature range from 3 to 44 °C. So, for example, the white house fungus *Coriollus sinuosus* in the temperature range of 6–37 °C, the membranous house fungus *Coniophora cerebella* – 8–37 °C [5]. The optimal temperature for the development of wood-destroying fungi, according to various sources, lies in the range of 18–36 °C [9], 25–35 °C [10], 20–36 °C [18]. Thus, for example, the optimal temperature for the development of the true house fungus *Merulius lacrymans* is 18–23 °C, and that of the membranous house fungus *Coniophora puteana* is 23 °C [18]. At lower temperatures, the activity of wood-destroying fungi slows down significantly, and at temperatures below -5 °C they die [11].

No less important factor in the growth of wood-destroying fungi than air temperature is the moisture content of wood. Wood-destroying fungi can only grow in certain wood moisture ranges. For various wood-destroying fungi, the moisture content of wood is different. Most wood-destroying fungi can develop in the range from 20 to 120 % [5]. The optimal humidity is 30–70 % [19]. At a low moisture content, the development of fungi is greatly slowed down, and at a value below 20 %, it completely stops. House fungi do not develop on dry wood (humidity up to 12 %) and on wood that is in an air-dry state (humidity 15–20 %). In a semi-dry state (humidity 23–25 %), the wood is affected by the real house fungus *Merulius lacrymans*. In a damp state (25–30 %) and at high humidity (30–60 %), wood is destroyed by all types of wood-destroying fungi [10]. For example, the membranous house fungus *Coniophora puteana* infects wood at a moisture content of 30–50 %, the white house fungus *Coriolellus sinuosus* – 35–55 % [18]. The most demanding on moisture is the mine fungus *Paxillus acheruntius*. It grows at wood humidity of 50–70 % and air humidity of about 100 % [19].

At the initial stage of wood biodegradation, decomposition proceeds slowly, but as wood-destroying fungi grow and the area of affected wood increases, wood-destroying fungi no longer need moisture from outside, and can develop due to the so-called "biological moisture", which is formed as a result of their vital activity and wood destruction [5], [20].

Due to the fact that wood has the property of hygroscopicity, its moisture content depends on the humidity of the surrounding air. At maximum air humidity (100 %), wood moisture reaches the saturation point of the fiber, i.e., the maximum amount of hygroscopic water possible for it. In coniferous trees, the moisture content of wood, corresponding to the saturation point of the fiber, is in the range of 29–31 % [19]. Wooden buildings and structures are moistened mainly by atmospheric precipitation and soil and ground moisture. The more air humidity, the more moisture wood absorbs, but not higher than 29–31 %. Thus, high air humidity contributes to the maintenance of wood moisture that is optimal for the development of wood-destroying fungi and at the same time makes it possible for spores to germinate, the mycelium to develop and favors fruiting bodies to form. Wood-destroying fungi develop best at a relative humidity of 75–100 %.

In addition to the above factors, the presence of oxygen affects the growth of wood-destroying fungi. Spore germination and mycelium development can only occur in the presence of oxygen. This explains the fact that wood immersed in water does not decompose due to the fact that all cells are filled with water, and they do not have the oxygen necessary for spore germination [5]. For the development of wood-destroying fungi, oxygen access is required in an amount of at least 20 % of the wood volume [11]. Reducing the amount of oxygen in wood to a certain minimum causes a delay in the growth of mycelium [9].

The growth of most wood-destroying fungi proceeds best in diffused light but can also occur in the dark. This is confirmed by the development of wood-destroying fungi in ceilings, attics, undergrounds of buildings and structures where light does not penetrate. The action of direct sunlight has a detrimental effect on the spores of some wood-destroying fungi. Lack of light also has a harmful effect on the development of wood-destroying fungi, especially on the development of their fruiting bodies [9].

4. Conclusion

An analysis of studies of decomposition and destruction process of wood by wood-destroying fungi, methods of protection and supervision of the appearance and spread of foci of wood decay allows us to draw the following conclusions: wood-destroying fungi, in the course of their vital activity, destroy the main components of the cell walls (cellulose and lignin) of wood, which act as a frame or skeleton, perceiving the impact of external loads. In the process of biodegradation of cell walls in wood, cracks and voids appear, leading to a decrease in the effective area of its cross section. Which in turn leads to a decrease in the physical and mechanical characteristics of wood. The intensity and nature of the change in the physical and mechanical characteristics of wood depend on the natural and climatic factors of the environment, the most significant of which are the temperature and humidity of the air, as well as the moisture content of the wood. In the range of air temperature from 18 to 36 °C, air humidity from 75 to 100 % and wood moisture from 23 to 70 %, the process of wood biodegradation proceeds most intensively, and the physical and mechanical characteristics of wood decrease to minimum values. At lower or higher values of air temperature, air humidity and wood moisture, the biodegradation process slows down or stops at all.

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Conflict of Interest

None declared.

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