FORESTRY

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Gavrilov T.A.*
ORCID: 0000-0003-3671-0971,

Petrozavodsk State University, Petrozavodsk, Russia

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

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STUDY OF PATTERNS OF TIMBER MOISTURE CHANGES IN THE PROCESS OF ITS DECAY

Research article

Abstract

The article is devoted to the topical problem of decay of wooden architecture monuments. The article describes the methodology and results of the experimental study of changes in timber moisture content in the process of decay for samples at different decay stages. During the research the regularities describing the change in the timber absolute moisture content over time, as well as the rate and smoothness of the change in the timber absolute moisture content have been obtained. It was found that the timber absolute moisture content samples not subject to decay varies in a small interval corresponding to the absolute moisture content of air-dry wood. The timber absolute moisture content of samples in the initial and developed decay stages increases continuously, and the speed and smoothness of the change in the timber absolute moisture content depends on the decay stage. The obtained results are prerequisites for early determination of the process of timber decay, allowing to prevent the destruction of wooden architecture monuments.

Keywords: timber, decay, wood-destroying fungi rotting, timber moisture content, wooden architecture monuments, carbohydrate hydrolysis, timber decay stages.

Гаврилов Т.А.*
ORCID: 0000-0003-3671-0971,

Петрозаводский государственный университет, Петрозаводск, Россия

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

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ИССЛЕДОВАНИЕ ЗАКОНОМЕРНОСТЕЙ ИЗМЕНЕНИЯ ВЛАЖНОСТИ ДРЕВЕСИНЫ В ПРОЦЕССЕ ЕЁ ГНИЕНИЯ

Научная статья

Аннотация

Статья посвящена актуальной проблеме гниения памятников деревянного зодчества. В статье описывается методика и результаты экспериментального исследования изменения влажности древесины в процессе её гниения для образцов, находящихся на разных стадиях гниения. В ходе исследования получены закономерности, описывающие изменение абсолютной влажности древесины с течением времени, а также скорости и плавности изменения абсолютной влажности древесины. Установлено, что абсолютная влажность древесины образцов неподверженных гниению варьируется в небольшом интервале, соответствующем абсолютной влажности воздушно-сухой древесины. Абсолютная влажность древесины образцов, находящихся в начальной и развитой стадиях гниения увеличивается непрерывно, причем скорость и плавность изменения абсолютной влажности древесины зависит от стадии гниения. Полученные результаты являются предпосылками для раннего определения процесса гниения древесины, позволяющими предотвратить разрушение памятников деревянного зодчества.

Ключевые слова: древесина, гниение, дереворазрушающие грибы, влажность древесины, памятники деревянного зодчества, углеводный гидролиз, стадии гниения древесины.

1. Introduction

In the process of operation, wooden architecture monuments are subjected to decay, which causes their destruction, leading to significant material losses, and may cause their partial or complete loss as objects of cultural heritage [1].

Currently, to identify the decay process of monuments of wooden architecture methods of external inspection of their

wooden structures are used [2], [3]. These methods include visual inspection of the interior of wooden architecture monuments, special attention is paid to such rooms as ground floors, attics, areas of possible leakage of atmospheric moisture. Areas affected by decay are determined by changes in color and structure of timber [4], [5]. The disadvantage of these methods is that the color of timber changes only at the end of the initial or developed decay stages. In connection with this, these methods allow you to identify the decay process only with a significant lesion of timber structures, which is a significant problem to be solved.

Timber decay is caused by the activity of wood-destroying fungi [6], [7]. Wood-destroying fungi secrete special enzymes, under the action of which timber decomposition occurs, described by the formula [8], [9]:

$$C6H10O5 + 6O2 \rightarrow 6CO2 + 5H2O.$$

Thus, during the process of timber decay, water release occurs, and, consequently, the timber moisture content is constantly increasing. In this regard, we can assume that the increase in timber moisture content is an indicator of the emergence of the process of timber decay, allowing you to identify this process at the beginning of its inception. This proposal is a hypothesis of the research. In order to verify the hypothesis it is necessary to study the patterns of change in the timber moisture content during the decay process.

The purpose of the research is to study the patterns of change in the timber moisture content of wooden architecture monuments in the process of its decay.

2. Methods

To measure timber moisture content, temperature and air moisture, special devices consisting of: *1* – digital timber absolute moisture content sensors LM393 (measuring range 8.8 to 54.8 %, measuring accuracy ± 1 %), *2* – digital temperature and air relative moisture sensors GY-SHT31-D (measuring range –40 to 125 °C, measuring accuracy ± 0.01 °C, measurement range of air relative moisture 0 to 100 %, the accuracy of air relative moisture 0.01 %), *3* – controllers with integrated Wi-Fi module (ESP32 DevKit V1 30pin), *4* – power supplies (or storage batteries) and a number of accessories (Figure 1). The Testo 606-2 moisture meter (measuring range from 8.8 to 54.8 %, measuring accuracy ± 1 %) was used for calibration of timber absolute moisture content sensors and control of measured timber absolute moisture content values (Figure 2).

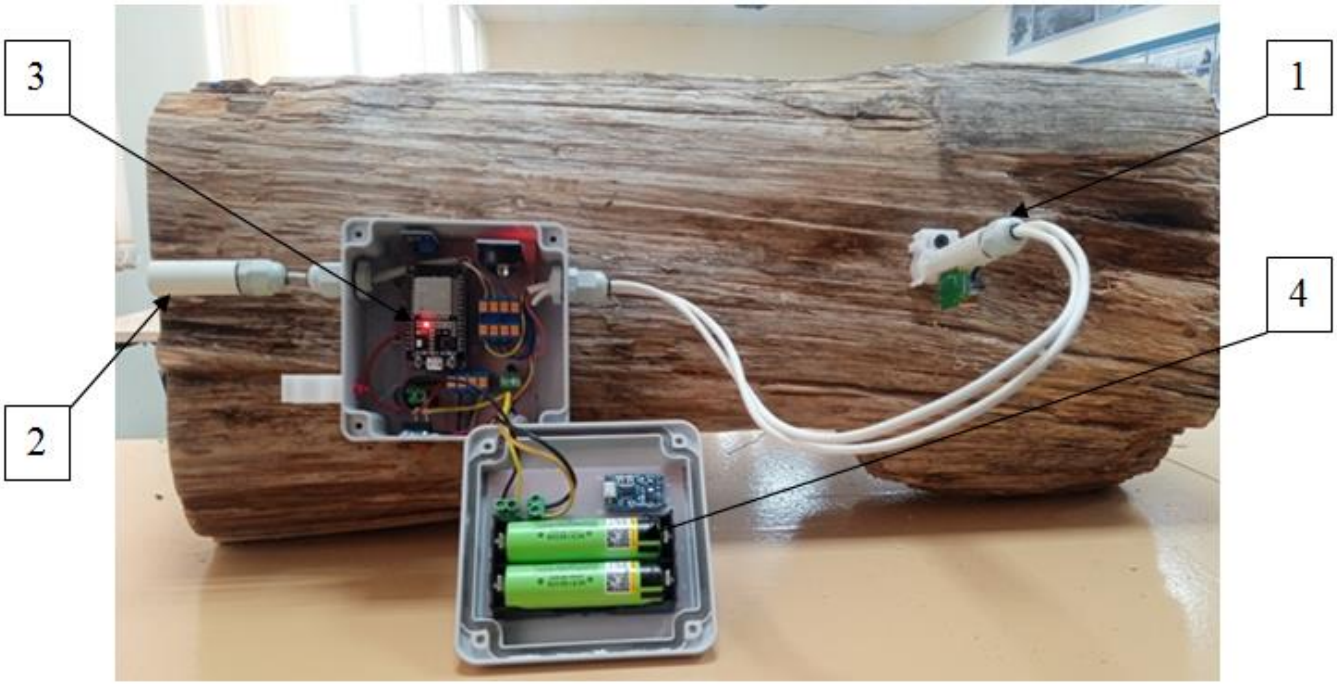

Fig. 1 – Instrument for measuring timber moisture content, temperature and air moisture:
1 – digital timber absolute moisture content sensors LM393; *2* – digital temperature and air relative moisture sensors GY-SHT31-D; *3* – controllers with integrated Wi-Fi module (ESP32 DevKit V1 30pin),
4 – power supplies (or storage batteries) and a number of accessories

Fig. 2 – Measuring the timber absolute moisture content with a moisture meter Testo 606-2

The principle of operation of the devices is as follows: sensors 1 and 2 continuously measure data on timber moisture content, temperature and air moisture and transmit them to the controllers 3, which store these data and transmit them to the computer via a local Wi-Fi network at a certain interval.

Samples of structural elements of wooden architecture monuments with different timber decay stages were chosen as objects of research (Figure 3): 1) no decay (samples No. 1, 5, 7), 2) the initial decay stage (samples No. 2, 6, 8); 3) the developed decay stage (samples No. 3, 4, 9).

Fig. 3 – A number of samples of structural elements of wooden architecture monuments

During the research, on each sample of structural elements of wooden architecture monuments were installed manufactured devices that continuously measured and stored the values of timber absolute moisture content, temperature and relative air moisture for 2 months and transmitted the measured data to the computer via a local Wi-Fi network.

3. Results

During the research, we obtained data on the timber absolute moisture content, temperature and relative air moisture for three groups of samples with different decay stages. The obtained data were processed using generally accepted methods of mathematical statistics. The results are presented in the graph (Figure 4).

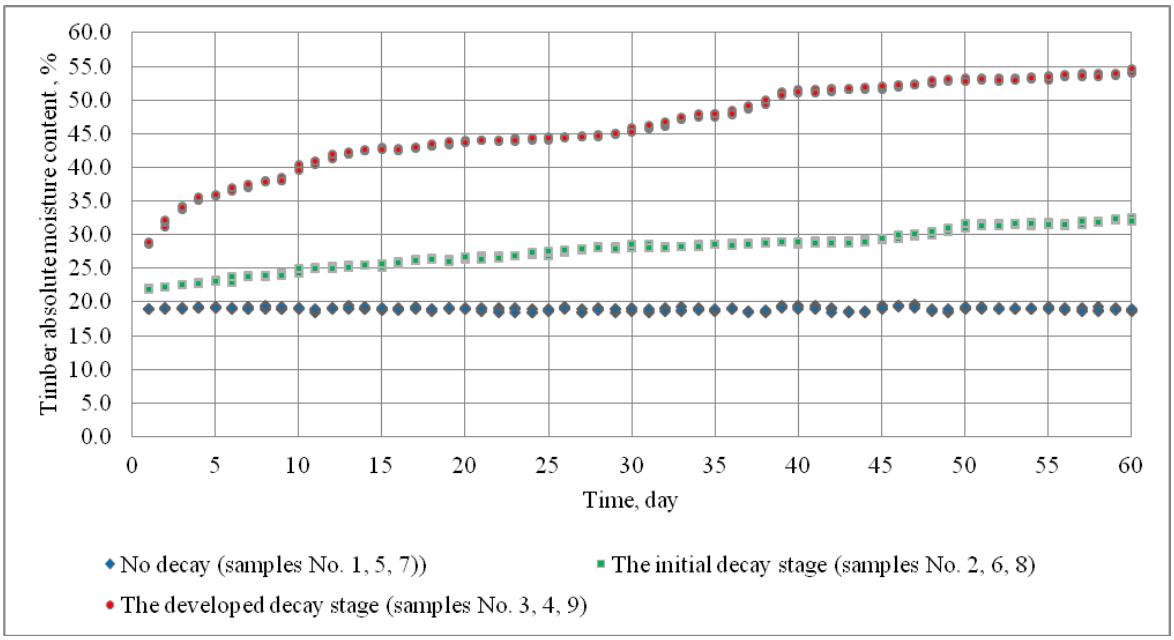

Fig. 4 – The graph of changes in the timber absolute moisture content over time

Air temperature during the research ranged from 21.31 to 28.23 °C. Air moisture varied in the range from 40.66 to 55.07 %.

Analysis of the results presented in Figure 4 shows that the timber absolute moisture content samples No. 1, 5 and 7 (no decay) throughout the research changes slightly in the range from 18.4 to 19.6 %, which corresponds to the absolute moisture content of air-dry timber. Timber absolute moisture content samples No. 2, 6 and 8 (the initial decay stage) during the research continuously grows from 21.9 to 32.5 %. By the end of the research the growth was 48 %. Timber absolute moisture content of samples No. 3, 4 and 9 (the developed decay stage) during the research also grew continuously from 28.5 to 54.6 %. By the end of the research the growth was 92 %.

The results presented in Figure 4 can be approximated by dependencies characterizing the relationship between the timber absolute moisture content (W) and the duration of the decay process (t):

– the initial decay stage

$$W = 0.16 \cdot t + 22.89,$$

(approximation reliability $R^2 = 0.970$);

– the developed decay stage

$$W = -0.01 \cdot t^2 + 0.61 \cdot t + 32.86,$$

(approximation reliability $R^2 = 0.964$).

The rate of change in the timber absolute moisture content can be determined as follows:

$$V_W = \lim_{\Delta t \to 0} \frac{\Delta W}{\Delta t} = \frac{dW}{dt}.$$

Then, the rate of change in the timber absolute moisture content, is equal:

– the initial decay stage

$$V_W = \frac{dW}{dt} = \frac{d(0.16 \cdot t + 22.89)}{dt} = 0.16 \text{ % / day};$$

– the developed decay stage

$$V_W = \frac{dW}{dt} = \frac{d(-0.01 \cdot t^2 + 0.61 \cdot t + 32,86)}{dt} = -0.02 \cdot t + 0.61 \text{ % / day}.$$

The smoothness of the change in the timber absolute moisture content can be determined as follows:

$$a_W = \lim_{\Delta t \to 0} \frac{\Delta V_W}{\Delta t} = \frac{dV_W}{dt}.$$

Then, the smoothness of the change in the timber absolute moisture content, is equal:
– the initial decay stage

$$a_W = \frac{dV_W}{dt} = \frac{d(0.16)}{dt} = 0 \ \% / \text{day}^2;$$

– the developed decay stage

$$a_W = \frac{dV_W}{dt} = \frac{d(-0.02 \cdot t + 0.61)}{dt} = -0.02 \ \% / \text{day}^2.$$

The results are consistent with the ideas known from the literature about the timber decay process [10], [11], [12].

4. Conclusion

The analysis of the results allows us to draw the following conclusions:

1) Timber absolute moisture content samples not subject to decay changes insignificantly, and the value corresponds to the absolute moisture content of air-dry wood;

2) Timber absolute moisture content samples exposed to decay in the initial and developed stages continuously increases;

3) Timber absolute moisture content samples exposed to decay at the initial stage increases gradually at a constant rate of 0.16 % / day. The change in the timber absolute moisture content can be described by the equation $W = 0.16 \cdot t + 22.89$.

4) Timber absolute moisture content samples subjected to decay in the developed stage increases intensively. Moreover, the rate of change in the timber absolute moisture content slows down and the smoothness of the slowing down is 0.02 % / day2. Change of timber absolute moisture content can be described by the equation $W = -0.01 \cdot t2 + 0.61 \cdot t + 32.86$.

5) The results of the research confirm the validity of the hypothesis that the change in timber moisture content is an indicator of the occurrence of the process of timber decay, allowing to identify this process in the beginning of its genesis. The obtained results are prerequisites for the early determination of the process of timber decay, allowing to prevent the destruction of wooden architecture monuments.

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Conflict of Interest

None declared.

Конфликт интересов

Не указан.

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