Research of the process of water absorption by thermally modified wood

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Abstract. The analysis of the process of thermal modification of wood, which was obtained by a controlled process of pyrolysis of wood heating (> 180 °C), which causes some chemical changes in the structures of cell wall components (lignin, cellulose and hemicellulose), to increase its durability. It is proved that in the process of thermal modification there is a decomposition of hemicelluloses and amorphous part of cellulose, reduction of water absorption, and also the quantity of substances which are the environment for development of fungi decreases. In addition lignin and pseudolignin formed by the process of polymerization and redistribution in cell volume and cell walls provide higher density, hardness, increase the hydrophobicity (water repelling), thereby reducing their ability to absorb moisture and swell. Polymerised lignin fills the inside of the cell – formed closed porous structure with low ability to bind water. It was established that the most effective option to reduce such substances are temperature and exposure time. The results of water absorption, dependence on which the calculated diffusion coefficient in the water absorption. Thermal modification of wood reduces water absorption by more than 10 times within 6 hours, which allows it to be used on objects with high humidity.

1. Introduction
It is possible to increase the level of operation of facilities where wooden building structures are used by modifying it, the essence of which is to give the wood the ability to resist moisture, the spread of biodamage, which contributes to the destruction of wood and accelerate the destruction process. Given the above, when modifying wood there are difficulties with the technological modes of its processing, namely, as time, temperature. This is primarily due to the fact that the modification process may not be achieved, and the use of thermodified wood leads to its destruction [1].

Knowledge of physicochemical properties of thermo-modified wood, indicators of its quality, mechanism of action on temperature materials, allows to make a choice taking into account economic indicators, duration and safety of application, ecological aspects, etc. [2, 3]. And the use of protection allows you to maintain their functions during operation for a specified period of time [4-7].

Therefore, development of technological modes of modification of wood, water absorption investigation, the impact of the structure of wood, this process is insoluble component ensuring the stability of building structures of wood and determine the need for resistance to fracture.

2. Analysis of recent research and publications
In recent years, in the direction of research on thermal modification of wood, there are works aimed at studying the equilibrium moisture during modification, dimensional stability, durability and mechanical properties of modified wood [8]. Mass loss, wettability, wood color, and chemical transformations have since been extensively studied, while work is needed to focus on quality control, modeling, and the study of the causes of improved wood properties.
Thermomodified wood is one of the best materials for lining [9]. Due to this humidity measurement conducted thermally modified heat and low moisture content of thermally modified wood in comparison with the standard spruce. But no, that was the extent and modes of modification of wood.

Increased use of thermally modified wood [10] led to the need for reliable quality control, including control of products deviations within certain limits, allowing you to control third party in the event of certification and regulation of the complaints and demands of consumers. However, it is not specified what methods are needed to characterize the change in quality in terms of improved target properties of modified wood during industrial production.

A study of changes in swelling and surface roughness of wood alder and elm normal after heat treatment at two different temperatures and duration [11]. It was found that the parameters of swelling and surface roughness differed significantly for two temperatures and two durations of heat treatment. The values of swelling and surface roughness decreased with increasing processing temperature and processing time, but did not specify the technological parameters.

The characteristics of wood due to weather conditions change over time, especially the color, which reflects chemical changes [12]. The change of color and reflectivity of wooden surfaces due to artificial weathering, obtained with the help of a solar box chamber, which simulates external conditions and subsequent leaching of water, was carried out. As the weathering time increases, the untreated surfaces of the wood samples darken, while the modified samples lighten to have a similar color or, in any case, to reduce the chromatic difference that was at the beginning of the weathering tests.

During the heat treatment is many chemical reactions that lead to changes in the components of the primary cell walls of wood and darkening material. Among other changes, thermodified wood is more resistant to fungal decay and more stable at times than untreated, making it suitable for use indoors and outdoors as cladding, flooring, floors, garden furniture and window frames [13].

Laboratory tests have shown a positive effect of thermal modification on the durability, dimensional stability and thermal conductivity of wood [14]. The monitoring results showed that the elements and windows of thermally modified spruce have a significantly lower moisture content in the wood compared to windows of unmodified, and that the wax also has a positive effect on humidity.

Natural aging is usually a relatively slow process because the artificial aging plays a role important in assessing the results by reducing the time compared to the natural weathering conditions. The approach is to protect the surface with various types of commercial products such as water-based solvents with a high solids content, powder coatings and substance-free products [15].

One approach is wood modification, a set of processes that give the treated material more ability to cope with damage caused by the external environment by increasing the duration of treatment. The process is also performed to enhance the physical, mechanical or aesthetic properties of wood and derived products with the advantage that they are not as harmful to users and the environment as natural wood [16].

Thus, from the literature it is established that thermal modification of wood is able to withstand destruction. All this gives grounds to say that it is advisable to conduct a study to determine the parameters that provide resistance to water absorption by thermodified wood. Therefore, research in this area is the unresolved part of ensuring the sustainability of building designs, which resulted in the need for research.

3. The purpose of this work
The purpose of this work is to study the diffusion of moisture in wood and establish effectiveness against water absorption during thermal modification.

4. Materials and methods of research
Samples of untreated and thermomodified hornbeam wood with a size of 25×20×20 mm were used to establish the diffusion of moisture by wood after thermal modification. Heat treatment of wood was performed at a temperature of 200 °C for 1 to 6 hours (Figure 1).
Figure 1. Model samples of hornbeam wood for testing: 0 - untreated; heat-treated at a temperature of 200 °C for: 1 – 1 hour; 2 – 2 hours; 3 – 3 hours; 4 – for 4 hours; 5 – for 5 hours; 6 – for 6 hours.

To obtain the values of moisture diffusion in wood, special equipment was developed and manufactured (Figure 2).

The test sample was fixed in a special cuvette so that it was in a humid environment above the water (Figure 2).

Figure 2. Device for testing the absorption of moisture by wood.

After a certain period of time, the sample was weighed on scales and the amount of water absorbed was determined.

5. Modeling of moisture diffusion parameters by wood
Since the effect of changing the moisture concentration in the sample is in the range from $C_{\text{max}}$ to $C_f$ (Figure 3), the value of the diffusion coefficient in this zone can also be considered insignificant, which gives reason to assume the moisture diffusion coefficient constant throughout the process of moving the front from the body surface to its center.

The advance of the phase transformation front in most processes, as a rule, is very slow, so the distribution of moisture across the spent zone in the first approximation is entrusted to the corresponding stationary distribution at the instantaneous position of the front. For a flat body, such a stationary profile is linear.

Consider the water absorption of a flat body with a thickness of $2h$, on the surface of which a constant moisture concentration $C_{\text{max}}$ is maintained, and on the moving front of the phase transformation with a coordinate $Z(\tau)$, a constant concentration $C_f$ value is set throughout the process.
Figure 3. Scheme of promotion of the moisture front in the capillary-porous material (wood):
1 – external environment with a humidity of 100%, \( x<0 \); 2 – area of the wood sample with
humidity, \( 0<z\leq Z(\tau) \) (\( Z \) – coordinate of the water absorption front, m); 3 – material of the wood
sample, \( Z\leq z\leq h \) (\( h \) – half the thickness of the sample, m).

The process of diffusion of moisture into the wood in the stationary approximation can be
described by the equation of the form:

\[
\frac{\partial^2 C}{\partial x^2} = 0, \tag{1}
\]

with boundary conditions: at \( x=0 \), \( C=C_{\text{max}} \); at \( x=Z(\tau) \), \( C=C_f \) gives the following distribution of
concentration on the surface of the sample:

\[
C = C_{\text{max}} - \frac{C_{\text{max}} - C_f}{Z} \cdot x. \tag{2}
\]

The amount of moisture entering the wood can be described by:

\[
C_1 = C_{\text{max}} \cdot \frac{Z}{h}, \tag{3}
\]

where \( C_1 = C_{\text{max}} - m(\tau) \cdot C_{\text{max}} \).

Taking into account (3) the amount of moisture remaining in the wood is described by the
following relationship:

\[
m(\tau) = 1 - \frac{Z}{h}. \tag{4}
\]

The derivative of the dependence (2) gives the rate of change of mass in the coordinate:

\[
\frac{\partial C}{\partial x} = \frac{C_{\text{max}} - C_f}{Z}, \tag{5}
\]

and the amount of moisture absorbed by the wood during time \( d\tau \) and responsible movement front
\( C_{\text{max}}dz \) value that corresponds to the intensity of moisture absorption equation:

\[
C_{\text{max}} \cdot \frac{dz}{d\tau} = D \cdot \frac{C_f - C_1}{Z}. \tag{6}
\]
The integration of which under the initial condition \( Z|_{\tau=0} = 0 \) gives the coordinate for the current coordinate of the front:

\[
Z = \sqrt{2D \cdot \frac{C_f - C_1}{C_{\text{max}}} \cdot \tau}.
\] (7)

The proportion of moisture in the wood corresponds to:

\[
1 + m(\tau) = \sqrt{\frac{2D}{h^2} \cdot \frac{C_f - C_1}{C_{\text{max}}} \cdot \tau}.
\] (8)

Given the quasi-stationary process of moisture diffusion, the concentration of the substance at the front of the phase transformation can be considered as follows:

\[
C_f = C_1 + \frac{C_{\text{max}}}{C_f} (C_{\text{max}} - C_1).
\] (9)

Given the above, the proportion of moisture in the wood can be calculated by the equation:

\[
m(\tau) = 1 + \sqrt{\frac{2D}{h^2} \cdot \frac{C_{\text{max}}}{C_f} \cdot \tau}.
\] (10)

Relation (10) can be used to experimentally determine the diffusion coefficient if the relative humidity in a material, such as wood, is measured during the experiment.

6. Research results
In the Table 1 shows the results of water absorption by wood.

| № sample | Exposure time, days |
|----------|---------------------|
|          | 0  | 1  | 2  | 5  | 6  | 7  | 8  | 12 | 21 | 26 |
| 0        | 7.41 | 8.01 | 8.35 | 8.74 | 8.72 | 8.75 | 8.73 | 8.75 | 8.76 | 8.76 |
| 1        | 7.55 | 8.03 | 8.31 | 8.52 | 8.59 | 8.54 | 8.57 | 8.63 | 8.70 | 8.72 |
| 2        | 7.34 | 7.81 | 7.99 | 8.31 | 8.35 | 8.35 | 8.38 | 8.33 | 8.38 | 8.38 |
| 3        | 7.38 | 7.87 | 8.07 | 8.29 | 8.32 | 8.33 | 8.30 | 8.44 | 8.45 | 8.44 |
| 4        | 7.11 | 7.52 | 7.72 | 7.99 | 8.11 | 8.00 | 8.07 | 8.11 | 8.12 | 8.12 |
| 5        | 7.16 | 7.56 | 7.74 | 7.87 | 7.89 | 7.93 | 7.99 | 7.99 | 7.99 | 8.00 |
| 6        | 7.01 | 7.39 | 7.6 | 7.76 | 7.8 | 7.81 | 7.79 | 7.86 | 7.86 | 7.86 |

According to the obtained experimental data, the share of moisture in the wood that was thermomodified was calculated, which are shown in Figure 2.
Figure 4. Change of water absorption of thermmodified wood: 0 - untreated; heat-treated at a temperature of 200 °C for: 1 – 1 hour; 2 – 2 hours; 3 – 3 hours; 4 – for 4 hours; 5 – for 5 hours; 6 – for 6 hours.

After measuring the tangent of the angle of inclination of the obtained line, the diffusion coefficient (D) is calculated for known values $C_1$, $C_{\text{max}}$ and $h$ as a function of:

$$D = \frac{h^2}{2} \cdot \frac{C_{\text{max}}}{C_1} \cdot \tan^2 \alpha,$$

(11)

which is for wood depending on the time of thermal modification, Table 2.

Table 2. The value of the diffusion coefficient in water absorption of thermmodified wood.

| Indicator | Time of thermal modification of wood, hours |
|-----------|--------------------------------------------|
| Moisture diffusion coefficient, $m^2/s$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|          | 0.024916 | 0.00045 | 0.00044 | 0.00013 | 0.00011 | 0.00004 | 0.000006 |

As can be seen from the table, when the wood is thermally modified for 6 hours, the water absorption is reduced by more than 10 times, which allows it to be used on objects with high humidity.

7. Conclusions
The obtained dependences allow, on the results of experimental researches, to carry out calculations of coefficient of diffusion of moisture in wood and to establish norms of application of a building design. The results of the research will also allow to purposefully solve further problems related to the creation of new means and methods of protection of organic materials and conditions of their operation at various sites.

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