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INFLUENCE OF CLIMATIC AGING ON OPERATING PROPERTIES OF FIBERBOARD

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Statement of the problem. The objective of the study is to reveal the influence of climatic factors (heat aging, UV irradiation, humidity) on the performance of fiberboard.
Results. The results of experimental studies of the operational properties of fiberboard exposed to moisture, heat aging, and UV radiation are presented. The research results are based on the main provisions of the thermal fluctuation theory.
Conclusions. The set of studies carried out sufficiently demonstrates the effect of climatic aging on the performance properties of fiberboard. During research, it was revealed that climatic aging has a detrimental effect on fiberboard, namely, the bonds between the filler particles are broken, because of which there is a complex decrease in the strength and resistance of the material to other climatic influences.

Keywords: humidity, fiberboard, heat aging, thermal fluctuation, UV irradiation.

Introduction. At present, fiberboard is commonly used in construction practice. This material is used in residential and industrial construction as thermal insulation, sound insulation and as a finishing material [3, 5]. Fiberboard (GOST 4598-86) is a sheet material that is made by hot pressing or drying wood fibers with the addition of binders and special additives, depending on the required parameters [1]. Such plates are produced with a length of 1200—3600 mm, a width of 1000—1800 mm. Hard slabs have a thickness of 3—8 mm, and soft slabs 8—25 mm [13].

Fibreboards are classified:

— according to the method of production: wet, dry, wet-dry and semi-dry;

— in appearance: unilateral and bilateral smoothness;

— by density: hard and soft;

— by type of front surface;

— for machining: rusticated with longitudinal and transverse grooves, perforated with round or slotted holes, ground and unpolished [14].

1. Rationale for the study. During operation, all building materials are subject to external influences (moisture, low and high temperatures, ultraviolet, etc.). The action of external factors can cause aging of building materials, i.e., to a change in their structure, as well as deteri oration in their performance properties (strength, heat resistance, etc.) [7—9]. There are currently no sufficiently large volumes of data on the influence of these impacts, and the beha-vior of the material over time has not been studied at all. The relevance of this study is in identifying the effect of external factors on the properties of fiberboard and taking into account the results obtained while predicting long-term strength. In order to obtain reliable results, a generalized formula of the thermofluctuation theory is used [16]. This formula allows one to take into account the simultaneous effect of temperature, time and load, as well as external influences.

2. Foreign and domestic experience. In world practice, while studying strength characteristics, the limiting values of strength were obtained for various types of loading (transverse bending, compression, tension, penetration, etc.) under normal conditions [4, 15]. In the process of manufacture and operation, the material is under the influence of long-term loads, which result in their deformation and destruction [2]. At the same time, other factors also act on the material (temperature and humidity, atmospheric effects, solar radiation, etc.) [10—12].

The study of the physical and mechanical properties of fiberboard was carried out by such scientists as V.D. Beketov, E. D. Mersov, A. A. Leonovich, I. G. Korchago, S. L. Rebrin, I. A. Otlev, V.M . Khrulev, etc. Also, the physical and mechanical characteristics of fiberboard with modernizing additives that affect fire resistance, moisture resistance, etc. are presently being studied [6]. Foreign authors are also actively investigating the physical and mechanical properties of fiberboard [19, 20]. It should be noted that researchers in some countries are looking at the properties of adapted types of fiberboard for local raw materials [17, 18, 22]. E.g., in [21], the use of bamboo filler with modernizing additives was considered.

It should be noted that in some works attempts were made to study the long-term strength of fiberboard, but without taking into account the joint work of various impact factors. Consideration of the long-term strength using the generalized formula of the thermal fluctuation concept will make it possible to obtain more accurate results [16].

3. Description of the study. The processes of influence of climatic aging on the operational characteristics of fiberboard are described using the generalized formula of the thermal fluctuation theory. The generalized formula physically substantiates the fourth constant T_m, which describes the limiting temperature at which the durability τ_m is minimal:

$$\tau = \tau_m \cdot \exp\left[\frac{U_0 - \gamma \cdot \sigma}{R} \cdot \left(T^{-1} - T_m^{-1}\right)\right], \qquad (1)$$

where τ_m is the durability of the material or the time to the onset of one of the limiting states, sec; R is the universal gas constant, kJ/mol·K; σ is the stress, MPa; T is the temperature, K; τ_m, U_0, γ, T_m are physical constant of the material [16].

The study of the impact of climatic aging on the performance of fiberboard includes 6 stages of research. The first study is aimed at identifying the possibility of breaking bonds in the material under the action of UV irradiation and thermal aging. This dependence is revealed by studying the absorption of liquid media by the material and its swelling. Water significantly affects the characteristics of wood composites, in addition, it is the most common liquid medium, so the study is carried out with its use.

Determination of fiberboard resistance to UV irradiation is carried out in a special chamber for artificial photoaging. The heat aging process is carried out by heat treatment in an oven. Water absorption is given by the formula:

$$B = \frac{m_н - m_к}{m_н} \cdot 100 , \tag{2}$$

where $m_н$ is the mass of the sample prior to testing, kg; $m_к$ is the mass of the sample after being in water, kg.

Swelling of the material throughout the thickness is given by a similar formula:

$$B = \frac{c_н - c_к}{c_н} \cdot 100 , \tag{3}$$

where $c_н$ is the height of the sample prior to testing, m (cm); $c_к$ is the height of the sample after being in water, m (cm).

The second stage determines the effect of UV irradiation and thermal aging on the rate of fiberboard swelling. In order to identify the rate of swelling, graphs of the influence of heat aging and UV radiation for swelling is reconstructed by graphic-analytical differentiation into the coordinates of the logarithm of the swelling rate from the reciprocal temperature. In order to describe them, an Arrhenius type equation is used:

$$w = w_0 \cdot \exp\left(-\frac{E}{RT} \right), \tag{4}$$

where w is the swelling speed, %; w_0 is a pre-exponential factor, %/c; E is the activation energy (swelling or excessive swelling), kJ/mol; R is a universal gas constant, kJ/(mol·К); T is the temperature, К.

The third stage is aimed at revealing the effect of UV radiation and swelling on the thermal expansion of fibreboard. The study involves constructing dilatometric graphs based on experimental data. The shape of dilatometric curves in the transition region shows the structures of macromolecules and the supramolecular structure of the polymer, which makes it possible to investigate the nature of transitions in copolymers, branched and cross-linked polymers.

The fourth study determines the effect of temperature on fiberboard strength before and after UV radiation. The test involves transverse bending of fiberboard elements at various temperatures before and after UV radiation. The samples are loaded stepwise on a six-position stand and their critical load is fixed. Based on the experimental data, a graph is constructed in the coordinates of the critical stress versus temperature.

The fifth study shows patterns of fiberboard behavior during penetration. Tests are performed in the mode of given constant voltages before and after UV radiation at different temperatures (20, 40, 60 °C). The experiment is conducted using a lever setup with a large lever length. The immersion depth is fixed by a dial indicator. The thermal fluctuation constants describing the introduction of an indenter into the surface of a material are obtained in the course of standard graphic-analytical reconstructions. Based on the obtained experimental data, graphs were plotted in the coordinates lgτ – σ. The next step was the standard rearrangement of the family of fan-shaped lines in the coordinates lgτ – 1000/T. The constants τm and Tm are determined from the pole of these lines. The constants U0 and g are found from the graph plotted in the coordinates U0 – σ. The constant U0 is the value formed along the ordinate (U0, kJ/mol) by the point of intersection of the straight line, and g is the slope of the straight line, taken with the opposite sign.

At the final stage, the influence of humidity on the durability of fiberboard is studied. Samples are pre-soaked in water for 1 hour. Then their bearing capacity is determined in transverse bending on a six-position stand in the mode of constant specified temperatures and stresses. Then, according to the obtained experimental data, a graph is constructed in the coordinates of the logarithm of durability from stress.

4. Results and discussion. The tests were carried out in water at constant temperatures (20, 40, 60°C) before and after exposure to heat aging and UV irradiation. Based on the results obtained, kinetic curves were constructed in the coordinates of water absorption versus the exposure time in water (Fig. 1) and swelling versus the exposure time in water (Fig. 2). The curves have an exponential form.

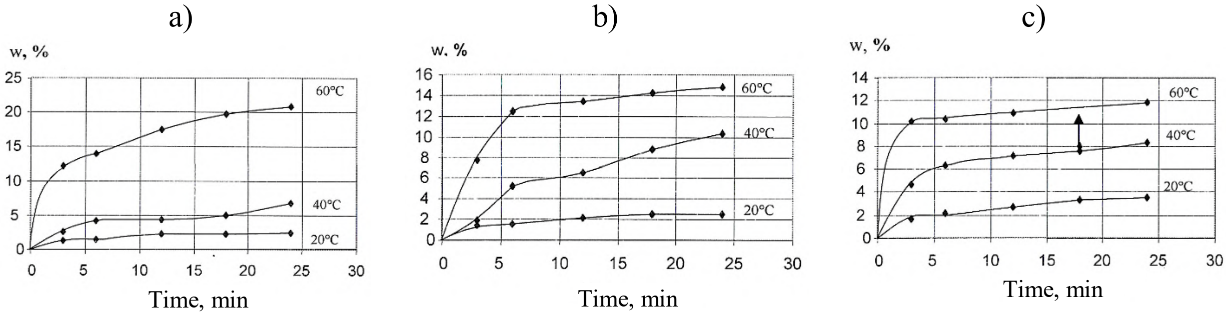

Fig. 1. Effect of thermal aging and UV irradiation on the water absorption of fiberboard:
a) without external influences; b) after UV irradiation; c) after thermal aging

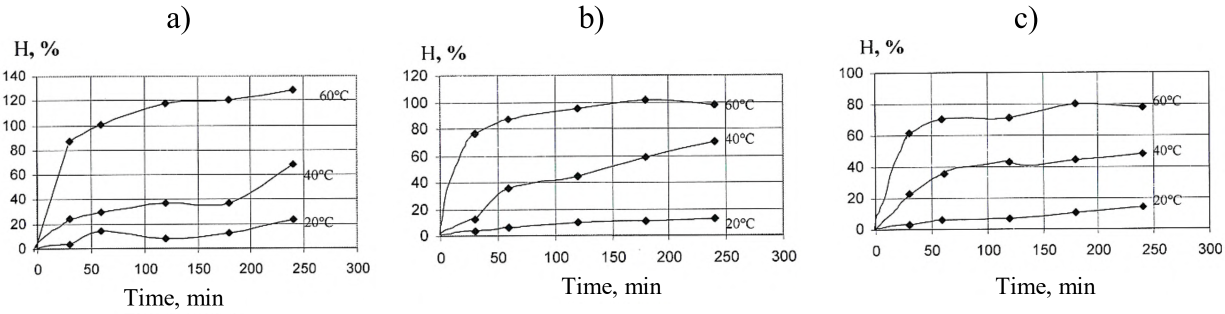

Fig. 2. Effect of heat aging and UV irradiation on fiberboard swelling:
a) without external influences; b) after UV irradiation; c) after thermal aging

It can be seen from the above graphs that the processes of swelling and water absorption proceed most strongly at the initial level (within 50—100 min), following which they slow down and stabilization occurs. At the same time, the temperature of the water strongly affects the rate of processes. Therefore when it is heated to 60 °C, the water absorption of fiberboard increases by 5 times.

Following the exposure to thermal aging and UV irradiation, the behavior of fiberboard in water changes. Based on the results, in fiberboard under the action of UV irradiation and thermal aging, there is a violation of the bonds between the filler particles. As a result, the materials become less susceptible to the action of water.

In order to identify the water absorption characteristics of fiberboard, the dependences of the swelling rate on the reciprocal temperature were plotted (Fig. 3). It can be seen from the figure that straight lines were obtained as a result.

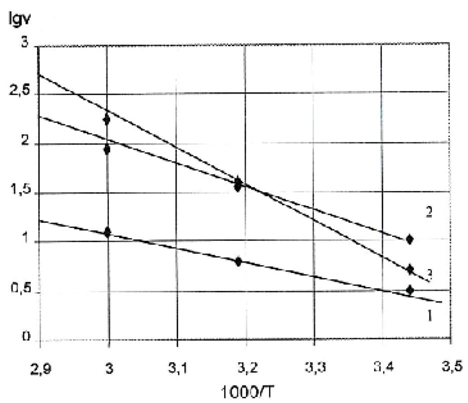

Fig. 3. Dependence of the rate of swelling of fiberboard in water from return temperature:
1 — no impacts; 2 — UV irradiation;
3 — thermal aging

The pre-exponential is identified by extrapolating this straight line to the y-axis (swelling rate), and the activation energy of this process is determined as the tangent of the slope of the straight line. The results are given in Table 1.

Table 1 shows that the constants characterizing the swelling rate change depending on the type of exposure. For fiberboard, the most dangerous type of impact is thermal aging.

Table 1

Values of physical constants of swelling of fiberboard

Type of impact	*E*, kJ/mol	lgv	*E*/lgv
No impacts	26.35	5.3	4.97
Following the UV-radiation	61.47	7.65	8.04
Following the thermal aging	35.13	11.55	3.04

The behavior of fiberboard in the free state upon heating at a given rate prior to and following UV irradiation and soaking in water was also investigated. The results are presented in Fig. 4 and 5.

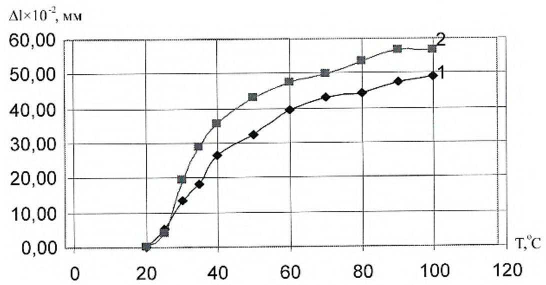

Fig. 4. Influence of the UV irradiation for linear thermal expansion of fiberboard: 1 — no impacts; 2 — following the UV irradiation

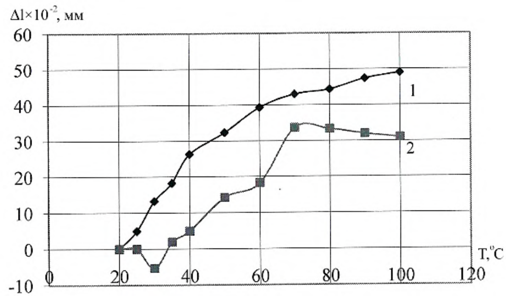

Fig. 5. Effect of swelling for linear thermal expansion of fiberboard: 1 — no impacts; 2 — after swelling

As can be seen in Fig. 4, the shape of the dilatometric curves does not change under UV irradiation. However, the linear change in the dimensions of the sample occurs more intensively.

As can be seen in Fig. 5, following the soaking, the form of dependences also does not change, but the intensity of expansion does change.

According to the obtained curves, the coefficients of linear thermal expansion were identified in Table 2.

Table 2

Values of the coefficients of linear thermal expansion of building composites

Type of impact	Coefficient of linear thermal expansion $\alpha \times 10^{-6}$, 1/°C
No impacts	121
Following the UV radiation	167
Following the swelling	111

The results of the effect of temperature on the strength of fiberboard are shown in Fig. 6. The figure shows that following the UV irradiation, the strength of fiberboard decreases significantly. Ultraviolet has a negative impact on the rosin emulsion and paraffin, which are part of the fiberboard binder, the bond between the fibers weakens, and they start operating as free ones. Thus, the necessary load required to break the material is reduced.

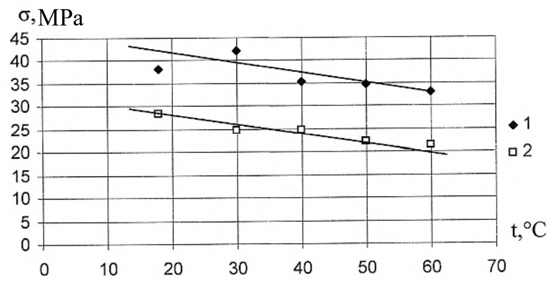

Fig. 6. Effect of temperature on the strength of fiberboard prior to and following the UV irradiation: 1 — no impacts; 2 — following the UV irradiation

According to the data from the graph, the temperature of fiberboard destruction without applying a load and the ultimate stress at a temperature equal to zero were calculated (Table 3). The value of the limiting temperature without application of load is obtained by means of interpolation on the abscissa axis. The value of the breaking stress at zero temperature is obtained by means of interpolation on the y-axis.

Table 3

Value of the temperature of the destruction of fiberboard without applying the load and the value of the limiting stress at a temperature equal to zero, with and without exposure to UV irradiation

Type of impact	t, °C, at $\sigma = 0$ MPa	σ, MPa, at $t = 0$ °C
No impacts	196	48
Following the UV-radiation	172	32

The results of penetration tests at temperatures of 20, 40, 60 °C in the coordinates lg $\tau - \sigma$ without external influences and following the exposure to UV irradiation are shown in Fig. 7.

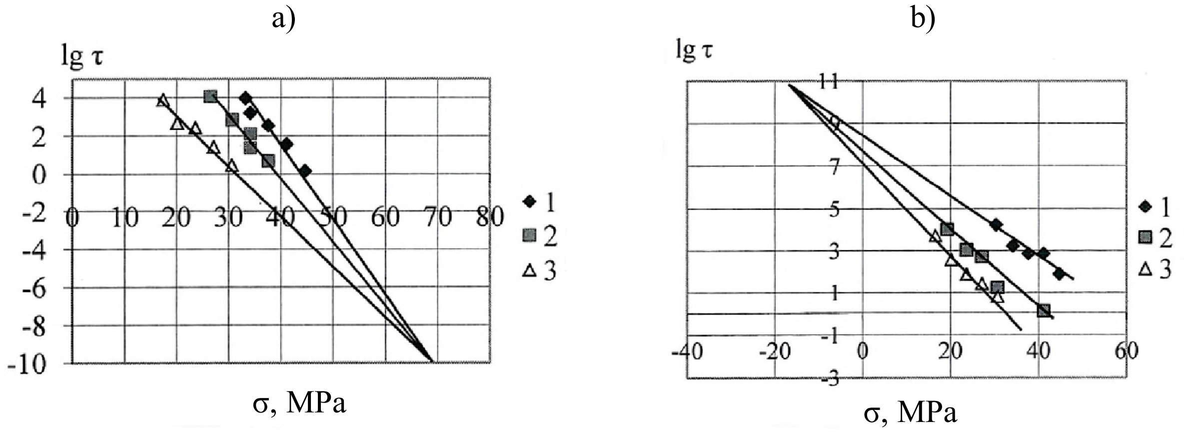

Fig. 7. Dependence of the logarithm of durability on stress and temperature for fiberboard: a) with no external influences; b) following the UV irradiation: 1 — at 20 °C; 2 — at 40 °C; 3 — at 60 °C

The dependences of the logarithm of velocity on the reciprocal temperature for fiberboard both before and after UV exposures are linear and converge at one point. This confirms the thermally activated nature of fiberboard deformation during penetration. Following the UV irradiation, the depen-dences took the form of backward beams. This character is described by means of the empirical equation of the backward beam:

$$\tau = \tau^*_m \cdot \exp\left[\frac{U^*_0 - \gamma^* \cdot \sigma}{RT} \cdot \left(\frac{T^*_m}{T} - 1\right)\right], \quad (5)$$

where τ_m^*, U_0^*, γ^*, T_m^* are empirical constants whose physical meaning has not yet been disclosed [16].

Fig. 8 and 9 show the graphs of the logarithm of durability versus reciprocal temperature and stress during penetration testing, as well as plots of effective activation energy versus stress with no external influences and following the impact of the UV irradiation.

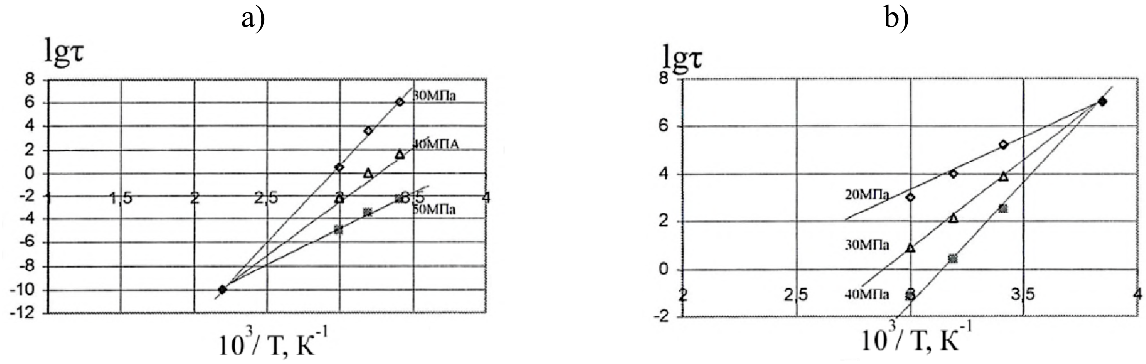

Fig. 8. Dependence of the logarithm of durability on the reciprocal temperature and stress for fiberboard: a) with no external influences; b) following the UV irradiation

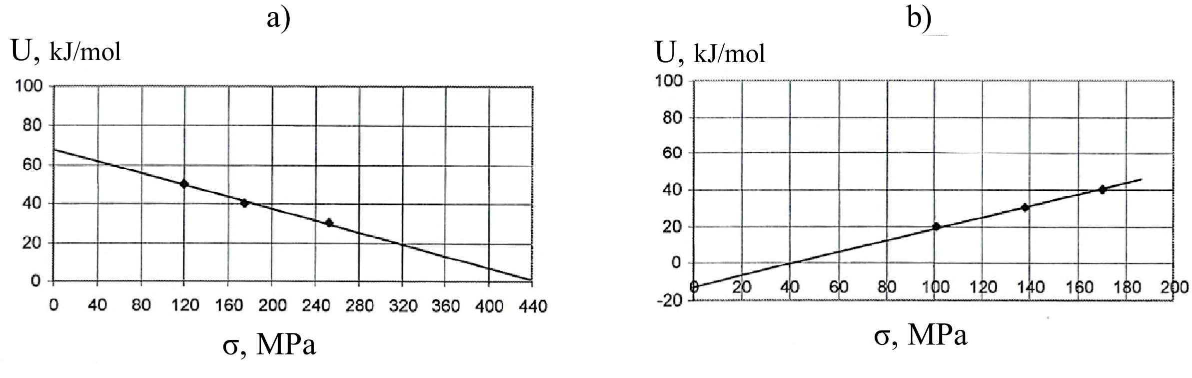

Fig. 9. Dependence of the effective activation energy on the voltage for fiberboard: a) with no external influences; b) following the UV irradiation

As a result of graphic-analytical reconstructions of these graphs, the thermal fluctuation constants presented in Table 4 are calculated.

These constants characterize the introduction of the indenter into the surface of the material during penetration. As can be seen, UV irradiation causes significant changes in the constants.

Table 4

Value of thermal fluctuation constants for fiberboard during penetration prior to and following the UV exposure

Type of impact	Thermal fluctuation constants			
	τ_m, sec	T_m, K	U_o, kJ/mol	γ, kJ/(MPa × mol)
No impacts	10^{-10}	455	68	6.47
Following the UV-irradiation	10^7	260	12	–3.33

In order to investigate the effect of water on the durability of fiberboard, long-term tests were performed The experimental data obtained in the log τ – σ coordinates are shown in Fig. 10.

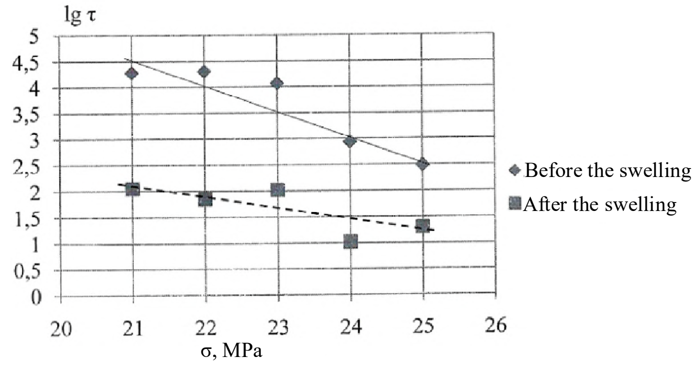

Fig. 10. Dependence of the logarithm of durability on the voltage for fiberboard before and after the swelling over 1 h

It can be seen that the nature of the dependences before and after the exposure to water is preserved, but there is a considerable loss of durability and strength. For fiberboard, there is a loss of 2 times.

Conclusions. According to the research results, it was found that the impact of both the UV irradiation and thermal aging lead to a breakdown of the bonds between the filler particles. This considerably reduces the ability of fiberboard to resist the influence of water.

It was found that the constants characterizing the swelling rate vary depending on the type of exposure (UV irradiation or thermal aging). For fiberboard, the most dangerous type of impact is thermal aging.

As the data suggests, the exposure to UV irradiation increases the coefficient of linear thermal expansion by 1.3 times, i.e., there is a decrease in the rigidity of the material. After soaking in fiberboard, the value decreased by 1.1 times, which indicates a slight increase in rigidity.

While investigating the effect of UV irradiation on the short-term strength of fiberboard, it was found that there is a sharp decrease in strength. This is due to the negative impact of ultraviolet radiation on its binder.

While investigating the effect of UV irradiation on the nature of the introduction of a solid indenter during penetration, thermal fluctuation constants were obtained, which make it possible to assess the degree of influence of this type of aging on durability. It has been established that after 50 hours of photoaging in fiberboard there is a change in thermal fluctuation constants accompanied by the transformation of the direct beam (dependence of the logarithm of durability on stress) into the reverse one.

While investigating the effect of fiberboard soaking in water for 1 hour on long-term strength, it was found that there is a decrease in durability. At the same time, the nature of dependencies is preserved.

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