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On issue of equivalence of methods of accelerated aging to natural by example of modeling climate impacts by freeze-thaw cycles

A V Erofeev, V A Mikhaylov

Faculty Magistracy, Tambov State Technical University, 112, Michurinskaya St., Tambov 392032, Russia

E-mail: av.erofeev@yandex.ru

Abstract. In this paper, the problem of establishing a correlation dependence between the actual operating conditions and accelerated aging of the material in the laboratory is set. As an example, the material considered is penoplex working in the system of ventilated façade for establishing the dependence of the selected strength in transverse bending. To find out the impact of climatic factors on the properties of the penoplex, a special stand was installed, which was operated in the conditions of the Tambov region for one year. As an accelerated aging, three alternate freeze-thaw schemes were considered. The schemes differed in the duration of soaking and freezing of the sample. The obtained results allow us to assert that various freeze-thaw simulation schemes lead to various changes in the characteristics of the material and before starting the simulation in each case it is necessary to establish an equivalent relationship.

1. Introduction

Currently, when studying the characteristics of building materials, great attention is paid to the issues of their change in the course of operation under the influence of a whole range of adverse effects. Knowledge of the dynamics of changes in characteristics during operation allows you to predict correctly the performance, including durability, of the material. Full-scale or accelerated tests are conducted for this purpose.

Under the full-scale are meant the methods and conditions of which provide obtaining the necessary amount of information about the characteristics of the properties of the object in the same time interval as in the provided operating conditions. Full-scale are tests of an object under conditions corresponding to the conditions of its use for its intended purpose with direct evaluation or control of the determined characteristics of the properties of the object. GOST 16504-81[1]. Full-scale tests are carried out in case of fulfillment of three main conditions:

1. Manufactured products (the test object) are directly exposed to tests without the use of models of the product or its component parts.
2. Tests are carried out in conditions and under the effects on products that meet the conditions and effects of use for the intended purpose.
3. The determined characteristics of the properties of the test object are measured directly, and no analytical dependences are used that reflect the physical structure of the test object and its

component parts. It is allowed to use the mathematical apparatus of statistical processing of experimental data.

Under the accelerated testing refers to the methods and conditions of which provide the required amount of information about the characteristics of the properties of the object in a shorter time than under normal conditions.

The most reliable method for determining the material's resistance to climatic factors is full-scale tests, during which their complex effect on the material under study occurs. However, a significant drawback of full-scale is the necessity of spending a large amount of time, which is not desirable in the conditions of the modern world and economy. That is why the most frequently used accelerated tests in which the material or product is investigated in laboratory conditions, simulating, for example, diurnal and seasonal climatic changes.

A significant number of researchers in determining the performance of building materials in their work use a variety of methods of artificial aging, based on accelerated testing in the laboratory. On the basis of the data obtained, predictions are made about the service life of a material during actual operating conditions. But, the works do not substantiate the equivalence relation between accelerated and natural methods of aging. The purpose of this work is to establish the equivalence between accelerated freeze-thaw cycles, modeled by different schemes, and the natural aging of the material in the ventilated facade system.

2. Research methodology

In order to determine how the environment affects the insulation working directly in the body of the enclosing structure of a residential building in the ventilated facade system, an experimental stand was designed [2,3]. The stand is a model of a ventilated facade lined with ceramic granite slabs[4]. Penoplex “comfort” was used as an insulation, the cladding is made of PVC panels with vertical and horizontal slots, which allow to simulate the gaps between the ceramic-granite plates[5-7]. Experimental stand is made in compliance with technical requirements. The stand was also made without a protective lining of insulation. A general view of the experimental stands is shown in Figure 1.

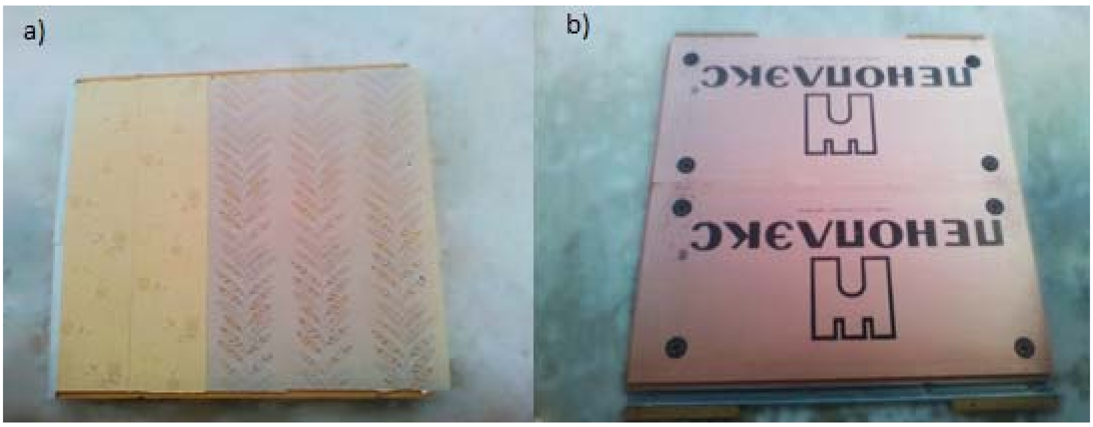

Figure 1. Model of the ventilated facade: a - with facing; b - without facing.

Stands are mounted on the outer wall of a residential building. The operating time of the stands in real conditions was one season, during which temperatures fluctuated from positive to negative values, as well as various atmospheric environmental factors such as ultraviolet radiation, precipitation, cyclic freezing and thawing[8]. After a specified amount of time has elapsed, the penoplex plates were removed from the stands and subjected to various tests to identify the physical and mechanical characteristics of the material [9]. The strength in transverse bending was chosen as the physicomechanical characteristics, although for a insulation operating in the system of a ventilated facade, it is not the main one, it is through it that the deterioration of the material parameters can be traced more clearly [10]. Physicomechanical characteristics were determined by standard methods. The revealed characteristics after the natural aging of the material during one season of work in the structure are to be compared with the characteristics of the penoplex subjected to accelerated aging by freeze-thaw cycles under laboratory conditions [11].

Accelerated aging cycles of freezing and thawing in the laboratory is carried out in three schemes, during each of which occurs a single soaking, freezing and thawing [12]. The experiment is carried out as follows: samples in the amount of thirty pieces (small beam size 120x30x25) are placed in the water for a specified time for this aging scheme, then removed from the water and placed in the freezer for a set time, after which the samples are removed and dried at room temperature to complete drying. After this cycle is repeated in the specified sequence[13]. In the course of accelerated aging, thirty cycles were performed within each of the schemes. Aging schemes are characterized by a certain amount of time spent by the sample in the soaking state and freezer. According to the first scheme, the time of soaking is one hour, the time of freezing at t = -20 ° C is also one hour. In the second scheme, the soaking time is two hours, the freezing time at t = -20 ° C is two hours. According to the third scheme, the soaking time is three hours, the freezing time at t = -20 ° C is three hours. Freezing is carried out in a freezer, temperature control is carried out using a thermometer. Changes in the physicomechanical characteristics were determined by standard methods after every 5 cycles.

The regularitiess obtained as a result of testing samples with different accelerated aging schemes are clearly presented in the Figure 2

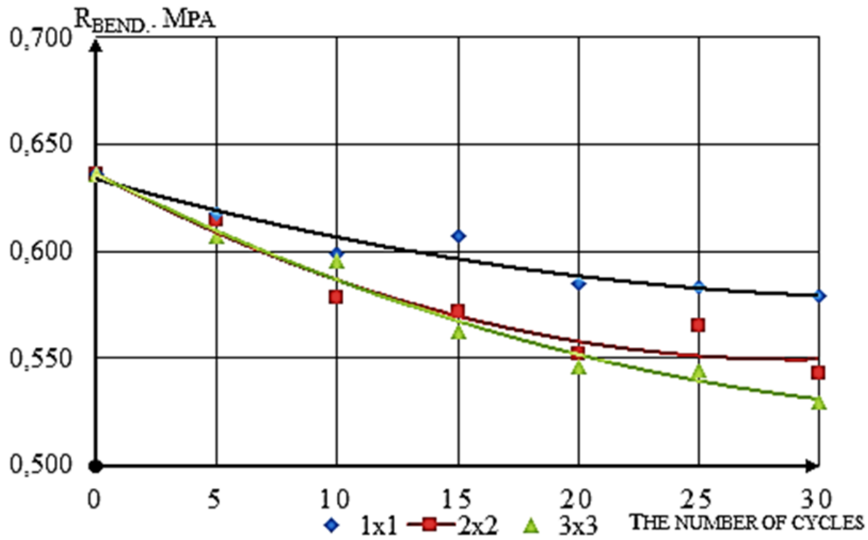

Figure 2. The graph of the dependence of the strength in transverse bending on the number of freeze-thaw cycles.

The dependence of the strength change in transverse bending for the 1x1 aging scheme is described by the equation:

$$y = 0{,}00005x^2 - 0{,}0032x + 0{,}634 \quad (1)$$

While the coefficient of approximation is R^2 = 0.9281. The strength values of the samples in the soaking state for 1 hour and under freezing conditions for 1 hour after 30 cycles amounted to 0.579 MPa, which corresponds to a drop in strength of 8.9%.

For the 2x2 scheme, the dependence of the change in strength during transverse bending is described by the equation:

$$y = 0{,}0001x^2 - 0{,}006x + 0{,}6365 \quad (2)$$

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The coefficient of approximation is $R^2 = 0.943$. After 30 freeze-thaw cycles with an aging scheme during which the sample spends 2 hours in a soaking state and 2 hours in the freezer, transverse bending strength is 0.543 MPa, which corresponds to a drop in strength of 14.62%.

For the 3x3 scheme, the dependence of the change in strength during transverse bending is described by the equation:

$$y = 0{,}00007x^2 - 0{,}0057x + 0{,}634 \quad (3)$$

The coefficient of approximation is $R^2 = 0.9807$. After 30 freeze-thaw cycles with an aging scheme during which the sample spends 3 hours in a soaking state and 3 hours in the freezer, transverse bending strength is 0.53 MPa, which corresponds to a 16.6% drop in strength.

From the graph presented in Figure 2, it can be seen that for the 1x1 and 2x2 schemes, a significant drop in strength in transverse bending is observed after 10 cycles and for the 1x1 scheme it is 5.8% of the initial strength. Whereas, after the next 20 cycles, the fall will be 3.16%. For the 2x2 scheme, a similar pattern is observed, after 10 cycles of freeze-thawing, the strength in transverse bending decreases by 9.12%, and after the next 20 cycles, the strength in transverse bending decreases by 5.52%. For the 3x3 scheme, a somewhat different picture is observed: after 10 cycles, the drop in strength is 6.3%, and after 20 subsequent strength decreases by 10.3%. Thus, the aging scheme for 3 hours of soaking, 3 hours of freezing, is the most unfavorable for the insulation penoplex, since it entails the greatest loss of strength during transverse bending after 30 cycles of freezing and thawing. The greatest loss of strength according to the 3 scheme can be explained by the fact that according to this method the samples spend more time in the soaking state, which entails more water absorption than the other schemes - saturation of the pores of the foam complex with water. The more saturated the material is with water, the more detrimental the freezing effect on penoplex [14]. This is due to the destruction of bonds in the polymer after repeated freezing and thawing, since this effect during the transition of water from a liquid to a solid state with an increase in volume leads to stress concentrators, which leads to disruption of bonds, resulting in a drop in cross-bending strength [15].

The graph shows that the strength curve for the 1x1 scheme differs from the curves for the 2x2 and 3x3 schemes, which immediately go down sharply and go almost parallel to the middle of the graph, and diverge only at the end, while for the 1x1 scheme, the curve drop is not so significant. From this it is necessary to conclude that if you increase the soaking time, you can find a threshold after which the mechanical strength of the foam plaster, which directly depends on the integrity of the insulation structure, will not decrease. Having reached the maximum water absorption, even with an increase in the soaking time, the mechanical strength parameters after cyclic freeze-thawing will not change. This assumption is based on the conclusions made earlier after analyzing the plot of the dependence of the strength in transverse bending on the freeze-thaw cycles. In particular, this can explain the similarity of the curves for aging schemes 2 hours of soaking 2 hours of freezing and 3 hours of soaking 3 hours of freezing.

When testing for transverse bending of specimens made from insulation of penoplex aged in real conditions on an experimental bench simulating a “ventilated facade”, the following data were obtained: the greatest drop in strength during transverse bending is observed under the conditions of material aging in the structures of a ventilated facade, the value of destructive stresses is 0.410 MPa corresponds to a drop in strength of 35.5%. Insulation that was without a protective lining on an experimental test bench showed a lesser decrease in strength during transverse bending. The value is 0.438 MPa, which corresponds to a 31.13% drop in strength. It is also worth noting that in the course of conducting full-scale studies, 23 times the actual transition through 0 °C for 1 year (2016) was recorded. Below is a table of values for transverse bending with different aging schemes and the number of freeze-thaw cycles (Table 1)

Table 1. Values of strength in transverse bending with different schemes of accelerated aging.

Type	1x1	2x2	3x3	Natural aging in ventilated facade
Rb. MPa				
1	2	3	4	5
initial	0,636	0,636	0,636	
5 cycles	0,615	0,588	0,607	
10 cycles	0,578	0,599	0,596	
15 cycles	0,572	0,607	0,563	0,410
20 cycles	0,552	0,585	0,546	
25 cycles	0,565	0,583	0,545	
30 cycles	0,579	0,543	0,530	

After the tests were carried out to identify the breaking load in transverse bending, on samples subject to accelerated aging and samples subject to natural aging, it was concluded that the accelerated aging schemes are freezing-thawing and natural aging in real conditions. It follows from it that 30 cycles of freezing and thawing correspond to less than 1 year of operation of the material in the system of the ventilated facade. The values of breaking load in transverse bending for a 1 hour soaking scheme 1 hour of freezing is 0.579 MPa, a drop in strength of 8.9%, for a 2 hour soaking scheme 2 hours of freezing 0.543 MPa, a drop in strength of 14.62%, 3 hours for soaking freezing 0,530 MPa, the drop in strength - 16.6%. Whereas, for the samples tested after real aging in the structures of the ventilated facade, the value of strength in transverse bending was 0.410 MPa, which corresponds to a drop in strength of 35.5%. The revealed data suggests that in order to identify the equivalent dependence of 1 year of operation in real conditions, it is necessary to increase the number of cycles of alternate freezing and thawing according to the 3x3 scheme, since this scheme has the most similar data from the results of the tests. Thus, the obtained results suggest that different freeze-thaw simulation schemes lead to different changes in the characteristics of the material and before starting the simulation in each case it is necessary to establish an equivalent relationship.

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