Assessment of Light Concrete Frost Resistance

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Abstract. Heat-insulating and structural-heat-insulating light concretes used in external enclosing structures significantly reduce the heat loss of a building in the cold season. The paper solves the problem of establishing criteria for evaluating the external walls made of light concrete blocks resistance to alternate freezing and thawing in laboratory conditions. A method for studying the frost resistance of masonry made of polystyrene concrete and cellular concrete of autoclave hardening during cycles of unilateral humidification-freezing-warming of wall fragments is proposed, which is closest to the actual operating conditions.

Physical, mechanical and thermophysical characteristics of heat-insulating and structural concrete are obtained. The dependences of heat-protective qualities on the degree of moisture content of the material, as well as the strength of the thawing conditions of samples in water and air conditions are established.

As the normalized parameters for assessing the frost resistance of light concrete masonry by unilateral freezing it is proposed to use the adhesion strength of blocks with plaster mortar, the strength of chemical anchors (breaking methods), as well as the passage speed of an ultrasonic impulse through the masonry thickness (non-breaking method).

Based on the research results, recommendations for their implementation in regulatory documents are formulated.

1. Introduction

Due to increasing regulatory requirements for the level of thermal protection of buildings, the demand for lightweight concrete with high thermal protection characteristics, in particular, for ultralight thermal insulation concrete with a density of up to 500 kg/m³, is constantly increasing. Research results and application experience show that heat-insulating lightweight concretes are significantly more reliable in maintenance comparing to layered insulation systems. There is an urgent need to improve the performance of thermal engineering quality of these concretes to raise the thermal protection properties of enclosing structures where they are used [1-3].

In the 50-60s of the XX century, the world's development rate of light concrete increased – the lower strength limit of high-strength concrete was 30 MPa. The development of revolutionary technologies has led to a general increase in the strength of lightweight concrete. In Japan, high-strength lightweight concretes with a density of 1800 kg/m³ and a strength of about 95 MPa were obtained on the basis of high-quality light aggregates with a maximum particle size of 15 mm. In China, in 2002, the standard "Light concrete. Technical rules" was published, strength classes LC55 and LC60 were introduced. In Russia, since 2000, polystyrene concrete and cellular concrete blocks of
autoclave hardening are actively used in frame buildings as self-supporting external walls (in some cases with an external insulation) [4-7].

2. Materials and methods
The ability of a water-saturated material not to break down under the influence of alternating temperatures is called a frost resistance. Quantitatively, frost resistance is estimated by marks equal to the number of cycles of alternate freezing and thawing, which the samples can withstand with a decrease in strength of no more than 5-25% and weight of no more than 5%. Frost resistance marks can vary in a wide range depending on the type of material, its composition, porosity characteristics etc. For example, for bricks, frost resistance marks are set in the range of F25–F150, for hydrotechnical concrete of F50–F500 [8-11].

Testing of water-saturated samples for frost resistance is carried out in refrigerating chambers by successive freezing of samples usually at a temperature of minus 20°C and thawing at 15 ... 20°C. In the most accessible capillary pores, water freezes at a temperature of minus 5 ... 10°C.

Frost resistance is the most important indicator that determines the exploitational stability and durability of building materials and products. While alternating freezing and thawing, the destructive effect of water in the material pores is especially great. Internal stresses arise in the material as a result of the ice crystallization process accompanied by an increase in its volume, that is cyclically repeated in the water-filled pores. As the cycles of freezing and thawing alternate, permanent deformations accumulate in the material, causing destruction [12-14].

To assess the parameters that affect the durability of external enclosing structures, as well as their normalization, it is necessary to have data on the characteristics of the construction area climatic activity. These include the following probabilistic and statistical data on outdoor air temperature and solar radiation at two active intervals of the year-winter-spring and summer-autumn (Fig. 1.):

— average monthly temperatures T, °C by the months of the year;
— the rate (°C/h) of changes in average monthly temperatures in their annual course;
— average daily temperatures on days of months of the year;
— average amplitude of A_s, °C of daily temperature fluctuations for months of the year with a half-period P_s = 12h.;
— average half-periods of stable periodic warming P_o and cooling P_3 in relation to the annual course of average monthly temperatures;
— the average amplitude of these warmings A_o and coolings A_s, °C;
— the average calendar date of the beginning of stable periodic warming in relation to the annual course of average monthly temperatures in the winter-spring year interval;
— the average calendar date of the beginning of stable periodic cooling in relation to the annual course of average monthly temperatures in the summer-autumn year interval.

![Figure 1. Scheme for reduction a periodic inharmonic graph of stable warmings and coolings to a harmonic graph.](image-url)
Figure 1 shows that a non-harmonic graph can be represented as the sum of a harmonic graph with an amplitude and half-period, and an additional phase and constant temperature shift \( t_{03} = (A_0 - A_S)/2 \), i.e. in the general case in the form:

\[
(t(\tau) - t_c(\tau)) = t_{03} + A_S \sin(\pi/P_{03})(\tau - \tau_{03})
\]

The winter-spring and summer-autumn intervals of the year are called its active periods at the specified time, during which there may be prolonged periodic warming and cooling with transitions of the external air temperature text(\( \tau \)) 0 °C. The average values of these parameters are given in the Set of rules and in the resources guide "Construction climatology" [8].

The research plan for frost resistance and durability of light concrete was made taking into account the fact that the properties of materials are influenced not only by the amplitude value of alternating temperature influences, but also by their cyclical nature. Moreover, this cyclicity can be approximated by a harmonic function.

Frost resistance studies were carried out for the two most currently used types of concrete for structural and thermal insulation purposes: cellular concrete of autoclave hardening and polystyrene concrete in the range of densities from 300 - 500 kg/m\(^3\) (Fig. 2 и 3). The method of determining the thermal conductivity of these concretes is shown in Fig. 4.

For cellular concrete and polystyrene concrete, there is a method for controlling frost resistance, in which the freezing sphere is air and the thawing sphere is air, but saturated with water vapor. The set number of cycles of alternate freezing and thawing (at a relative air humidity of 95±2%), in which the compressive strength of concrete is reduced by no more than 15% and the loss of mass of concrete samples - no more than 5%, is taken as the mark of concrete for frost resistance \( F \).

**Figure 2.** Volumetric freezing-thawing. Samples of cellular concrete (b) and polystyrene concrete (b) size 100x100x100 mm.

**Figure 3.** Testing of samples cubes of cellular concrete (a) and polystyrene concrete (b).
Figure 4. Thermal conductivity determination of polystyrene concrete and cellular concrete of autoclave hardening samples.

Frost resistance testing method of polystyrene concrete and cellular concrete of autoclave hardening samples while bulk freezing lies in the comparative evaluation of the cyclic stress effect during thawing as in full immersion in water and thawing in air with a relative humidity of 95±2%, at a temperature of 20 °C above zero. Freezing of samples in both cases occurs in the air chamber at a temperature of minus 20 °C [15–17].

3. Results

Studies of the thermophysical parameters of polystyrene concrete from two manufacturers and autoclave-hardened cellular concrete of D300–D400 density marks were conducted. It is established that the maximum sorption moisture content for polystyrene concrete is 14% by weight, and for cellular concrete it is 7% by weight.

The thermal conductivity of polystyrene concrete and cellular concrete of autoclave hardening samples was determined both in the state of natural humidity and in the dry state. The results are presented in the table 1.

Table 1. Averaged density and thermal conductivity values of polystyrene concrete and cellular concrete of autoclave hardening samples.

| Material                      | Average density value, kg/m³ | Averaged thermal conductivity values, W/(m K) |
|-------------------------------|-----------------------------|----------------------------------------------|
|                               |                             | \( \lambda_0 \) | \( \lambda_A \) | \( \lambda_B \) |
| Cellular concrete, D400       | 443                         | 0,112            | 0,13            | 0,18            |
| Polystyrene concrete, D300    | 315                         | 0,065            | 0,08            | 0,10            |

Tests for frost resistance were carried out in the KTK 3000 climate chamber. After a certain number of cycles, the cube samples were removed from the climate chamber for ongoing tests with an assessment of changes in compressive strength. Samples that were deposited in water were taken through 1, 3, 5, 10, 15, 20, 30, 40 and 50 cycles. Samples that were held in the air were taken through 5, 10, 15, 20, 30, 40, 50, 75, 100 and 150 cycles.

Samples of cellular concrete showed signs of destruction: peeling along the edges, loss of original geometric parameters. The samples were removed from the tests after the 15th cycle of thawing in water and after the 100th cycle of thawing in air. Samples of polystyrene concrete showed no signs of destruction.

The results of an experimental determination of the frost resistance of polystyrene concrete and cellular concrete of autoclave hardening samples during a bulk freezing are presented in the table 2.
Table 2. Results of an experimental determination of the samples strength after freeze-thaw cycles, when thawing with full immersion in water.

| Cycles | Average value of compressive strength, MPa |
|--------|------------------------------------------|
|        | Cellular concrete of autoclave hardening, D400 | Polystyrene concrete, D300 |
| 1      | 2.41                                      | 0.29                        |
| 3      | 2.24                                      | 0.29                        |
| 4      | 2.17                                      | 0.30                        |
| 10     | 1.84                                      | 0.30                        |
| 15     | 1.78                                      | 0.26                        |
| 20     | The samples show signs of destruction     | 0.22                        |
| 30     | The samples show signs of destruction     | 0.22                        |

When testing samples-cubes by volumetric freezing in the air with thawing in water and in the air with a relative humidity of 97%, it was found that polystyrene concrete during thawing in the air practically does not reduce the strength after 200 cycles of exposure. For this material, it is advisable to apply the test method according to GOST 10060-2012 (the first basic method).

Studies of the frost resistance of wall masonry made of polystyrene concrete and cellular concrete blocks by the method of unilateral freezing were carried out. According to the analysis results of data obtained during experimental studies, it was found that after 150 cycles of unilateral freezing-thawing-heating-humidification, the adhesion strength of blocks made of polystyrene concrete with a layer of external plaster increased by 7%, and blocks made of cellular concrete of autoclave hardening decreased by 27%. The tear-out strength of the chemical anchor in masonry from polystyrene concrete blocks increased by 14%, and from autoclave-hardened cellular concrete blocks decreased by 14%. The bond strength of polystyrene concrete blocks and autoclave-hardened cellular concrete blocks with masonry mortar and adhesive composition has increased, which indicates a continuing strength gain (mainly masonry mortar) under cyclic influences. In addition, the main area of the masonry mortar and glue zones was not affected by alternating influences, since it was located in the thickness of the masonry made of light concrete blocks with high thermal resistance.

When control the speed change of ultrasonic transit in a design's thickness was used a Pulsar 2.2 indicator. The speed of sound varies in average from 1520 m/s on a test piece of masonry) to 1180 m/s (after 150 cycles). This method of non-destructive testing can be recommended as a controlled frost resistance parameter of wall masonry made of light concrete blocks.

4. Discussions

The destructive effect of water is especially great when alternating freezing and thawing in the pores of the material. It is explained by the development of significant internal stresses in the material as a result of cyclical ice crystallization process in water-filled pores, accompanied by an increase in volume by 9%. At the same time, as the cycles of freezing and thawing alternate, permanent deformations accumulate in the materials, causing fatigue destruction. The intensity of destruction increases with increasing water absorption, the volume of open pores, lowering the freezing temperature, i.e., increasing, eventually, the volume of ice formed in the material.

Increasing the frost resistance of materials is achieved primarily by reducing the open porosity available for water, as well as increasing the volume of closed pores. Closed pores filled with air serve as "buffers" that weaken the pressure of the formed ice. Frost resistance increases with increasing water resistance of materials and their tensile strength [18-21].

According to the tests results of samples-cubes by the method of volumetric freezing in the air with thawing in the air saturated with moisture vapor, it was found that samples of polystyrene concrete practically do not reduce the compressive strength in the process of cyclic alternating influences. The specified method of assessing frost resistance for polystyrene concrete is not indicative. For this material, it is advisable to apply the test method according to the standard "Concretes. Methods for
determining frost resistance" (the first basic method) with thawing of samples when fully submerged in water.

The method of studying the frost resistance of masonry made of light concrete blocks during cycles of unilateral humidification-freezing-warming of wall fragments is closest to the actual exploitational conditions. When determining the frost resistance of masonry made of light concrete blocks by unilateral freezing, it is proposed to use the following controlled parameters: the strength of the adhesion of blocks with a plaster mortar and the strength of chemical anchors to break out (destructive methods), as well as the speed of an ultrasonic impulse passage through the thickness of the masonry (non-destructive method). The change in these parameters should be no more than 25% relatively to the value obtained on the control sample of masonry for destructive methods and to the initial value of the ultrasound speed when the main masonry sample is sounded through for the non-destructive method.

5. Conclusion
The global trend aimed at saving energy resources leads to the need to increase the regulatory requirements for the level of thermal protection of buildings. Heat-insulating and structural-heat-insulating light concretes used in external enclosing structures significantly reduce the heat loss of the building in the cold season. Requirements for the number of cycles of alternate freezing-thawing can be normalized differently, based on the climatic conditions of the territorial construction zone.

Research is the basis for the development of proposals for changes to the standard "Polystyrene concrete. Technical conditions" in terms of methods for testing frost resistance. When developing the national standard "Wall masonry of light concrete blocks. Methods for determining frost resistance", it is proposed to use the method of unilateral freezing of a fragment of masonry, while the controlled parameters are the strength of adhesion of blocks with plaster mortar and the strength of chemical anchors to break out (destructive methods), as well as the speed of passage of an ultrasonic pulse through the thickness of masonry (non-destructive method).

The results obtained in this work allow us to assess the overall service life of external wall masonry made of light concrete most accurately, predict the time before major repairs and minimize explotational costs.

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