Research of frost resistance of heavy polymer concrete modified by silica fume

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Abstract. Concrete is one of the most common construction materials. Strength and frost resistance are the main and most important properties of concrete. Frost resistance of concrete is very important for buildings and constructions erected in Russia, since many regions are characterized by harsh climate conditions. These climatic conditions include: low temperatures, fluctuations of both temperatures and humidity. As a result, concrete saturates with water, and after repeated alternating freezing and thawing, concrete may start damage. The idea of my scientific investigation is to develop a new technology of manufacture of the concrete possessing improved technical and operational characteristics, first of all, frost resistance. Within the frames of the present investigation, we studied the available experience of applying silica fume and polymers in concretes in the capacity of modifying additives used to elevate frost resistance. An optimal ratio of the additives was found, and the optimum composition of polymer concrete modified with silica fume was developed. Investigations bound up with determination of the principal physical and mechanical properties have been conducted.

1. Introduction
The climate conditions of any region are determined by various geographical properties such as geographical location, altitudes, reliefs, etc. When considering the climate conditions of Russia, one can state that the calendar year is roughly subdivided into cold and warm seasons. Substantial variations of the temperatures and humidity are characteristic of Russia, because the most part of Russia is characterized by the continental climate.

The climate of Irkutsk is characterized as sharply continental: long winters, low temperatures, precipitation and deeply freezing soil layers. The average temperatures of the cold period are from minus 15 °C to minus 33 °C, and for the warm period – from 17 °C to 19 °C. In this connection, in addition to the basic requirements to the construction materials used, there are special requirements added, first of all – frost resistance.

According to the state normative document, «concrete is an artificial stone construction material obtained as a result of molding and hardening of rationally selected and compacted concrete mixture» [1]. Despite the fact that concrete is a very durable material, it has a porous structure. As a result,
moisture can form in the pores. During the autumn period, concrete products and constructions are saturated with water and hence with minerals dissolved in it. Already after the first transitions through zero temperature, the water remaining in the pores crystallizes and increases in volume. This leads to formation of internal stresses and to the appearance of micro-cracks. The more cycles of alternating freezing and thawing take place, the faster is the process of destruction of the structural bonds inside the concrete block.

According to the state normative document, «frost resistance of concrete is the capability of concrete contained in a water-saturated solution or salt-saturated solution to withstand repeated freezing and thawing without exhibiting any external signs of destruction (cracks, chips, peeling of sample edges), any decreases in the strength, any changes in the weight and without variations of any other important technical characteristics» [2]. Frost resistance of concrete is determined depending on how many cycles of alternating freezing and thawing the sample withstood before destruction. The frost resistance grade of concrete is the indicator of its frost resistance, which corresponds to the number of freezing and thawing cycles of sample measured during the process of testing by the basic methods, under which the concrete characteristics fixed by this standard remain within the specified limits, and there are no external signs of destruction (cracks, chips, flaking of the edges of the samples) [2].

The low resistance of concrete to negative temperatures is due to its capability to absorb moisture from the environment, which later freezes and leads to destruction. The greater is the porosity of the concrete, the higher is its saturation with water. Furthermore, when exploiting concrete constructions under the conditions of high humidity, bacteria, fungi and mold can develop in the pores. The products of life activity of these microorganisms cause destruction of concrete. On account of our survey, one can conclude that there is a direct relationship between the density and strength of concrete: the higher is the density of concrete, the smaller is the number of pores (pores of small size) in it. It is obvious that dense concretes are more water-resistant and resistant to low temperatures [3-4].

So, there arises the problem of elevating the frost resistance of concrete. This can be achieved by observing the following recommendations:

- usage of high-quality cements of high grades,
- correctly computed and chosen water-cement ratio,
- lowering the concrete macro-porosity,
- observation of the technological modes of laying and compacting the concrete mixture,
- providing the care of concrete in the aspect of providing for optimal hardening conditions,
- usage of gas-forming and air-entraining additives for the concrete,
- application of waterproofing the concrete blocks.

The research problem consists in elevating the frost resistance of concrete for the regions with the continental climate. The approaches to solving this problem are:

1. Modification of concrete with polymers and ultrafine particles,
2. Development of the composition and the technology for producing heavy polymer concrete modified with silica fume.

The purpose of this investigation is to develop a technology for the production of frost-resistant heavy cement concrete with the use of silica fume.

The following tasks were defined to achieve this goal:

- development of an optimal concrete composition,
- investigation of the physicochemical processes of interaction between an ultrafine additive and a polymer;
- development of a technology for producing heavy polymer concrete modified with silica fume.

The scientific novelty of the author’s approach presumes:

1) combined usage of ultra-dispersed additives and a polymer, what is proposed for the first time;
2) the heavy cement concrete developed may be classified as concrete with special properties (polymer cement concrete).
2. Materials and methods

The purpose of the investigation is to obtain reliable results bound up with development of a technology for the production of frost-resistant heavy cement concrete using silica fume. Silica fume is a by-product of silicon production. The main advantages of using SF are to improve the structure of concrete and increase strength. The main disadvantage is that SF is a dispersed material that increases water consumption. To regulate the water-cement ratio and give the mixture additional positive characteristics, it is proposed to use a polymer. The joint use of these additives helps to increase the degree of hydration of cement [7-10].

Test methods regulated by regulatory and technical documents were used in order to determine the class of concrete in terms of frost resistance. The correspondence between the concrete frost resistance and the concrete grade in terms of strength is shown in Table 1.

Table 1. Compliance between the concrete frost resistance and the concrete grade with respect to strength/

| Concrete grade | Concrete class | Frost resistance, F |
|----------------|----------------|---------------------|
| M100, M150     | B-7.5, B-12.5  | F50                 |
| M200, M250     | B-15, B-20     | F100                |
| M300, M350     | B-22.5, B-25   | F200                |
| M400           | B-30           | F300                |
| M450, M550, M600 | B-35, B-40, B-45 | F200-F300          |

In order to obtain reliable results, an integrated approach was used to study and determine the class of concrete with respect to frost resistance.

To determine the class of concrete for frost resistance, the following specifications were used:
1. GOST 26633-2015 Heavy and fine-grained concretes. Specifications [11];
2. GOST 22685-89 Forms for the manufacture of control samples of concrete. Specifications [12];
3. GOST 10060-2012 Concrete. Methods for determining frost resistance (with amendments) [2];
4. GOST 31357-2007 Dry building mixtures based on cement binder. General technical conditions [13].

All the test methods for determining the frost resistance of concrete may be subdivided into the 2 groups: basic methods and accelerated methods [11].

The basic method (the first one, F1) is used for manufacturing of all types of concretes, the exception being represented by the concretes for road and airfield pavements, concretes for the constructions exploited under the action of saline water.

The basic method (the second one, F2) is used for manufacturing of concrete for road and airfield pavements and concretes for the constructions exploited under the action of saline water.

The accelerated method (the second one) is used for manufacturing of all types of concretes, except for the concretes used for road and airfield pavements, concrete structures operated under the action of saline water, and low-weight concretes with an average density smaller than D1500.

The accelerated method (the third one) is used for manufacturing of all types of concretes, except for the low-weight concretes characterized by an average density smaller than D1500. For the purpose of testing we have chosen the accelerated method (F2).

Determination of frost resistance of concrete samples was conducted according to GOST 10060 – 2012. This is an accelerated testing with repeated freezing and thawing.

In order to conduct investigations bound up with determination of frost resistance, concrete samples are made (a cube being with a side of 15 cm). Next, the sample is subjected to alternating freezing and thawing, and after that it is tested for strength. Freezing is carried out at the temperature of -18 degrees during 3-5 hours. Thawing is carried out at the temperature of +18 during the same time. If after testing it turns out that the average maximum admissible reduction in the mass of the samples does not exceed 2%, and the concrete does not lose its strength, then it corresponds to the declared frost resistance grade.
A batch of samples was made in the amount of 12 pieces: 6 samples for testing in the freezer, 6 samples as the reference ones (Fig. 1). According to Table 4 «Correlation between the number of test cycles and the grade of concrete with respect to frost resistance» from GOST 10060-2012, it was determined that it was necessary to program 8 cycles, which corresponded to the second method of accelerated type.

![Figure 1](image1.png)

**Figure 1.** Samples after 8 cycles in the freezer and samples after the strength test.

Destruction of specimens during compression tests can be of the two types: satisfactory and unsatisfactory. If a sample was destroyed according to one of the unsatisfactory schemes, the result was not taken into account.

According to Appendix E (reference) «Examples of fracture of samples during compression tests», Figure E.1 of GOST 10180-2012, the character of destruction of the sample cubes was recognized satisfactory (Figure 2) [14].

![Figure 2](image2.png)

**Figure 2.** Types of satisfactory destruction of sample cubes.

As follows from the experiments, if a concrete cube made of dense concrete has a fairly homogeneous structure and a regular geometric shape, then, when it destructs under the influence of a uniformly distributed load, it takes the form of two truncated pyramids.

Analysis of the test results allowed us to conclude that the samples endured the frost resistance test. The frost resistance grade was F2300.

3. **Principal results of this investigation**
1. Introduction of active mineral additives of silica fume increases the stability and homogeneity of the binder hydration products.

2. Introduction of the polymer has a plasticizing effect and allows one to reduce the water-cement ratio of the cement-concrete mixture.

4. Conclusion

Frost resistance is an important characteristic of concrete. It shows how many cycles of freezing and thawing the concrete can withstand, losing no more than 5% of its strength and no more than 2% of its mass.

The use of both silica fume in the composition of cements as an additive (which replaces part of the cement) and the polymer makes it possible to obtain frost-resistant concrete. Such concrete can be used in the construction of buildings and constructions in industrial and civil engineering, roads and other objects exposed to influences of water and negative temperatures, which may provoke destruction of concrete.

Concretes with frost resistance up to F50 are used mainly for interior and preparatory works.

Concretes with frost resistance F50–F150 demonstrate average values of frost resistance. Such concretes are good for construction of objects planned to be exploited under the conditions of mild climate.

Concretes with frost resistance F150–F300 are intended for construction in cold regions.

Concretes with frost resistance higher than F300 are used for construction under extremely cold conditions, as well as for erecting special purpose objects.

Addition of silica fume leads to the formation of low-basic calcium hydrosilicates, which are capable of restoring the structure of the cement stone when exposed to aggressive media. The usage of polymers makes it possible to regulate the water-cement ratio. The usage of silica fume leads to an increase in water demand, which is due to the fact that dispersion is of high importance, i.e. the greater is the dispersion of the material used, the greater is the water demand.

On the whole, we can conclude that the concrete composition elaborated may be used for erecting constructions in East Siberia and Central Siberia characterized by a sharply continental, harsh type of climate.

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