Portland cement foam concrete with a zeolite-containing mineral additive

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Abstract. The possibility of obtaining high-quality cement by an environmentally friendly (without CO₂ emission into the atmosphere) method of joint grinding of imported Portland cement clinker and local natural mineral raw materials in hard-to-reach areas of the North-East of the Russian Federation is substantiated. The results of an experimental study of the compositions and technological parameters of the manufacture of cement compositions based on portland cement clinker and active mineral additives from zeolite-containing rocks of Khonguruu, allowing non-autoclaved foam concrete with a density of 600-800 kg / m³ and compressive strength of 1.8-2.8 MPa with stable quality parameters are presented (monodisperse pore distribution and hardened inter-pore skeleton, providing stable values of density, strength and thermal conductivity).

1. Introduction

The development strategy of the Arctic and the North (the Far North according to Soviet terminology) provides for the development of the building materials industry with the maximum use of local raw materials [1, 2]. The main material for the purpose and scope of use for the construction of buildings and structures is structural and structural-heat-insulating (including non-autoclave foam concrete) cement concrete. High strength and durability of concrete, as well as reliability in the operation of structures and buildings in general, depends on the quality of Portland cement used. The most significant disadvantage of foam concrete on cement is the low degree of hydration of the binder, in contrast to autoclave production. A low degree of cement hydration, which is a consequence of insufficient crystallization of hydration products and can cause instability of density, structure and strength, shrinkage of non-autoclaved foam concrete during molding and hardening. Therefore, to eliminate these shortcomings, hydration and hardening accelerators, active mineral additives, special additives that reduce the water-hard ratio, and others are introduced into the initial foam concrete mixture.

Ensuring high and stable quality of Portland cement delivered to regions of the Arctic and the North remote from industrial centers is a difficult task due to the interaction of cement with air moisture (hydration) and loss of activity during transportation and long-term storage. The activity of Portland cement when stored in packaging bags in a marine climate decreases to 32% within 4 months, and after 62 months to 62% [3, 4].

In connection with this circumstance, it seems that in hard-to-reach regions of the Arctic and the North it is advisable to produce high-quality cement using environmentally friendly (without CO₂
emission into the atmosphere) by co-grinding imported Portland cement clinker and local natural mineral raw materials containing amorphous silica, glassy silica or silica in compounds (silicates, aluminosilicates, hydrosilicates and etc.) [5].

Based on the analysis of scientific and technical literature [6-12], the main working hypothesis is put forward on the possibility of ensuring the stable quality of foam concrete using Portland cement with active mineral additives from local raw materials due to their modifying effect on the basic properties of cement and concrete, related to the peculiarity of their chemical and mineralogical compositions.

Object of study - non-autoclave foam concrete on Portland cement with natural active mineral additives.

The subject of the study is natural raw materials with a high content of amorphous modifications of silica and zeolite mineral, the formation processes of the phase composition, structure and properties of foam concrete on Portland cement with natural mineral additives.

The effect of the content of mineral additives and the specific surface area of Portland cement was investigated. During research, the content of mineral additives varied from 5 to 15%, and gypsum content was 3% by weight of cement. For comparison, we also studied the properties of control samples based on the following cement compositions with active mineral additives from local raw materials due to their modifying effect on the basic properties of cement and concrete, related to the peculiarity of their chemical and mineralogical compositions.

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2. Materials and methods
As part of the development program for the Far Eastern region of the Russian Federation, it is planned to set up production of Portland cement on the territory of the ALROSA diamond mining company near natural bulk tonnage - zeolite-containing rocks of the Khonguruu deposit.

Therefore, we chose a zeolite-containing rock (hereinafter, zeolite) of this field as a mineral additive to cement. The chemical composition of the studied zeolite is characterized by a high content of silicon oxide. According to the mineralogical composition and X-ray diffraction pattern, it was found that the raw material is clean because it contains a small amount of clay impurities, mica and sand, belongs to the clinoptilolite (60.4% wt.) Type of mineral raw material and has pozzolanic activity [3]. The accelerating effect of zeolite on the hydration of C₃S and the early formation of C-S-H in cement stone was established in [7, 8].

Portland cement clinker JSC PA “Yakutcemement”. The mineralogical composition of clinker, % by weight: C₃S = 62–65; C₅S = 10–13; C₃A = 6–7 и C₄AF = 10–13. The chemical composition of clinker, % by weight: CaO – 66,0; SiO₂ –19,0; Fe₂O₃ – 3,9; Al₂O₃ – 3,7; MgO – 2,6; K₂O – 1,4; Na₂O – 1,2; SO₃ – 0,7.

As a regulator of setting time in Portland cement, gypsum stone of the Olekminsky deposit was used. The content of CaSO₄ ×2H₂O is 80,80 %.

For comparative analysis, control tests of samples of Portland cement JSC AO ”Yakutcemement” with a shelf life of 6 months or more in the accredited testing laboratory “Yakutsk-Expert” were carried out. It was found that the loss of activity of the brand CEM I 32.5 R is 31.7%, brand CEM I 42.5 R - 40.3%.

To establish the possibility of using zeolite as an active mineral additive in cement production, standard tests were carried out in accordance with GOST 25094-2015 (Russian standard certification). According to a statistical evaluation of the significance of differences in compressive strength of samples with the addition of zeolite and samples with standard multi fraction sand, it was found that mineral additives are active and can be used for the production of cements.

The effect of the content of mineral additives and the specific surface area of cement based on Portland cement clinker, gypsum stone, additives from zeolite on the properties of cement paste was investigated. During research, the content of mineral additives varied from 5 to 15%, and gypsum content - 3% by weight of cement. For comparison, we also studied the properties of control samples based on non-additive Portland cement.

The following cement compositions were used, % by weight
1 – clinker - 92, gypsum – 3, zeolite - 5;
2 – clinker - 87, gypsum – 3, zeolite - 10;
3 – clinker - 82, gypsum – 3, zeolite - 15;

The control composition is clinker 97, gypsum 3.
The reduction in the setting time of the cement paste and the acceleration of the initial structure formation of the stone are presumably due to the interaction of calcium hydroxide formed during alite hydrolysis with active additives from zeolite with the formation of low-basic hydrosilicates and calcium hydroaluminates. In accordance with the classification according to GOST 30515-2013 (Russian standard certification), the studied Portland cement with mineral additives in an amount of 5-15% is normally set.

The dependences of the compressive strength of a cement-sand mortar on the content of mineral additives are determined for various specific cement surfaces. It was found that the maximum strength of cement samples (45.6 MPa) is achieved for cement with 15% zeolite with a specific surface of 415 m²/kg. At the same time, Portland-pozzolana cement of the CEM II/A-P 42.5 N grade was obtained (GOST 31108-2016) (Russian standard certification) [3].

3. Results

Cement-based foam concrete with the addition of zeolite have compressive strength at 28 days of age 15-20% higher than foam concrete on factory cement CEM I 32.5 R (Fig. 1 a), and 11-15% higher than cement CEM I 42.5 R (Fig. 1 b). With an increase in the specific surface of cements from 315-330 m²/kg to 390-415 m²/kg, the strength characteristics of foam concrete do not change significantly, the increase in compressive strength is only 2.5-5.8%.

![Figure 1. Change in compressive strength and average density of foam concrete at different finenesses of grinding Portland cement with the addition of zeolite a - 315-330 m²/kg; b - 390-415 m²/kg.](image)

The curing strength of foam concrete samples at the age of 7 days is practically the same. Strength at 28 days of age for foam concrete on cement with a zeolite content is slightly higher. (Fig. 2 a) The results of experimental data indicate a uniform increase in shrinkage deformations during drying over the entire period. Shrinkage deformations of foam concrete (Fig. 2 b) occur intensively during the first 30 days, and then slow down. Shrinkage deformations of foam concrete on cements with mineral additives more than 30 days old are 0.2-0.35 mm/m less than foam concrete on cement CEM I 32.5 R. The developed non-autoclave foam concrete based on cement with a zeolite mineral additive has the following quality parameters: general shrinkage 2.2–2.6 mm/m, sorption moisture less than 7%, vapor permeability coefficient 0.14–0.15 mg/(m·h·Pa), frost resistance F25-F35, which meets the requirements of GOST 25485-89 (Russian standard certification).
The main parameters for the stability of the quality of foam concrete are the uniformity of the compressive strength index (GOST 18105-2010). According to the results of processing statistical data, it was found that in foam concrete with a medium density grade D600 on cement with zeolite addition, the coefficient of variation in compressive strength decreases from 15.6 to 5.6% (compared to foam concrete on CEM I 32.5 R more than 6 months of storage), and with a density of D800 - from 12.1 to 4.3%, which made it possible to obtain concrete with a compressive strength class of B1.5 and B2.5, respectively.

The increase in the strength characteristics of foam concrete can be justified on the basis of the theory of hydration of cement systems and experimental data obtained on the basis of x-ray phase analysis [3] and computer analysis of microphotographs (Fig. 3, d, e, f). As can be seen from them, in a cement stone having a coagulation microstructure, a decrease in the amount of ettringite is observed due to the binding of calcium hydroxide during the initial structure formation of foam concrete into sparingly soluble low basic hydrosilicates due to the presence of amorphous silica in quartz-feldspar sand.
The interaction of the cement composition with the surface of fine-grained sand introduced into the foam concrete mixture as a filler is clearly seen in the image of the microstructure of the foam concrete with a particle of sand (Fig. 4 a, b, c).

![Figure 4](image)

**Figure 4.** Microstructure of neoplasms at the phase boundary “sand aggregate-cement composition”.

The developed foam concrete based on cement from imported Portland cement clinker and mineral additives from zeolite is recommended for use in the production of structural and heat-insulating wall materials for the construction of buildings in areas of the Arctic and the North that are remote from industrial centers.

4. **Summary**

The results of experimental studies substantiate the working hypothesis about the modifying effect of an active mineral additive from a zeolite-containing rock of the Khonguruu deposit with a high content of a zeolite mineral - montmorillonite on the structure and properties of Portland cement and foam concrete based on them due to its pozzolanic activity.

Compositions and technological methods for preparing a foam concrete mixture based on a cement composition produced by joint grinding of Portland cement clinker (82-92% wt.), Gypsum stone (3% wt.) active mineral additives from zeolite-containing rocks of the Khonguruu field (5-15% wt.), with a fineness of grinding 315-415 m² / kg, fine aggregate (30% wt. over) in the form of fine sand, an aqueous solution of Etalon foaming agent (1:50), allowing to obtain non-autoclaved foam concrete with a density of 600-800 kg / m³ depending on W/T with a strength of 1.8-2.8 MPa with stable quality parameters (monodisperse pore distribution and hardened inter-pore skeleton, providing stable values of density, strength and thermal conductivity).

5. **References**

[1] Sarvut T O 2018 The principles of habitat formation in the Arctic region *Vestnik MGSU* 13 (2) 130-140

[2] Smirnova O O, Lipina S A, Kudryasheva E V 2016 Formation of support zones in the Arctic: methodology and practice *Arctic and North* 25 148-157

[3] Mestnikov A E, Kudyakov A I, Rozhin V N 2019 Portland cement with natural active mineral additives *Bulletin of Tomsk State University of Architecture and Civil Engineering* 21 (2) 192–201 DOI: 10.31675/1607-1859-2019-21-2-192-201

[4] Berdov G I, Ilyina L V 2010 Activation of cements by the action of mineral additives *International Journal of Applied and Basic Research* 9 55-58

[5] Leonovich S N, Sviridov D V, G.L. Schukin 2015 Composition of dry mix for non-autoclave foam concrete of natural hardening *Building Materials* 5 70-73

[6] T Perraki, E Kontori, S Tsivilis, G Kakali 2010 The effect of zeolite on the properties and hydration of blended cements *Cement and Concrete Composites* 32 128–133

[7] Martin Bohá, Dana Kubátová, Radovan Neasa, Anežka Zezulová, Alexandra Masárová, Radoslav Novotnýb 2016 Properties of cement pastes with zeolite during early stage of
hydration International Conference on Ecology and new Building materials and products, ICEBMP 2016 Procedia Engineering 151 2-9
[8] Klyuev S V, Klyuev A V, Shorstova E S 2019 Fiber concrete for 3-d additive technologies Materials Science Forum 974 367–372 DOI: 10.4028/www.scientific.net/MSF.974.367
[9] Mestnikov A, Semenov C, Strokov V, Nelluba V 2016 Autoclave foam concrete: Structure and properties Citation. AIP Conference Proceedings 2. Cep. "Advanced Materials in Technology and Construction, AMTC 2015: Proceedings of the II All-Russian Scientific Conference of Young Scientists Advanced Materials in Technology and Construction 070010.
[10] Klyuev S V, Klyuev A V, Shorstova E S 2019 The micro silicon additive effects on the fine-grassed concrete properties for 3-d additive technologies Materials Science Forum 974 131–135 doi:10.4028/www.scientific.net/MSF.974.131
[11] Bazhenov Y M, Zagorodnjuk L H, Lesovik V S, Yerofeyeva I V, Chernysheva N V, Sumskoy D A 2016 Concerning the role of mineral additives in composite binder content International Journal of Pharmacy and Technology 8(4) 22649-22661
[12] Volodchenko A A, Lesovik V S, Zagorodnjuk L H, Volodchenko AN, Aleksandrovna K A 2016 The control of building composite structure formation through the use of multifunctional modifiers Research Journal of Applied Sciences 10(12) 931-936