Cement based foam concrete with hardening accelerators

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Abstract. The results of studies of the effect of hardening accelerators on the properties of cement based foam concrete mix and foam concrete of natural hardening are given in this article. The study was conducted in the Laboratory of Tomsk State University of Architecture and Building which is accredited in accordance with the national standards requirements. It has been proposed to decrease the shrinkage deformations of the concrete mix and increase compressive strength of hardened foam concrete by affecting the cement matrix with the calcium chloride and calcium oxalate in the amount of 2 and 0.5% of the cement mass, respectively. This increases the aggregative stability and reduces the plastic shrinkage of the foam concrete mix by 47-65%. In foam concrete with the hardening accelerators the compressive strength rises from 0.31 to 0.47 MPa and from 0.96 to 1.44 MPa at the age of 28 days while maintaining the average density of D400 and D600 respectively. The developed composition of cement based foam concrete is recommended for constructing monolithic walls at a construction site or wall blocks in factory conditions for individual housing construction.

1. Introduction
Every year the building materials market expands and expands its range with new types. This contributes to the continuous development of production technologies. This factor has a positive effect on the quality of the material produced. In the conditions of the economic crisis, consumers are guided by material that allows them to save resources, both at the stage of construction of individual housing, and during its operation. Therefore, the construction of foam concrete blocks of natural hardening has gained particular relevance [1, 2]. The low thermal conductivity and energy intensity of the foam concrete wall blocks provide energy savings during the operation and construction of buildings and structures [1-5]. Shrinkage deformations, which adversely affect the quality of foam concrete, can be attributed to negative qualities. Shrinkage deformations lead to the formation of cracks in the products, which leads to a decrease in strength and an increase in the thermal conductivity of foam concrete. This fact greatly reduces the effectiveness of its use in wall structures of buildings [4-7].

Factors affecting the shrinkage deformation of foam concrete are as follows: hardening conditions (normal conditions, dry hardening, steam curing), foaming agent properties (foam stability, foam expansion), cement properties (w/c, type of cement), sand properties (content of harmful impurities, particle-size distribution), manufacturing process and equipment (time of aeration and mixing intensity of the mixture, sequence of loading components). Also one of the main factor affecting the quality of foam concrete wall blocks is the correctly selected technology for their manufacture. Today, there are many ways of preparing foam concrete, which have their drawbacks and advantages, which are difficult to accurately determine due to the wide variety of foam concrete mixtures production and the small amount of statistical data on the properties of the resulting foam concrete. Based on previous
studies and a literature review, the authors recommend the use of a one-stage technology for the preparation of foam concrete [5, 7].

The following shrinkage deformations are distinguished depending on the time of structure formation of foam concrete:

— contraction – is the result of the chemical interaction of concrete components with water and does not only change the external dimensions of the sample, but rather contributes to changes in the pore structure of the material: the volume of pores occupied by water decreases, air pores arise. Usually, this shrinkage develops during the hardening of concrete, when it is still sufficiently plastic, and therefore not accompanied by noticeable cracking of the material [8];

— drying shrinkage – is associated with a decrease in the moisture content of concrete, that is, with the evaporation of free water in a hardened cement paste and is caused by capillary phenomena. Drying shrinkage can lead to cracking in conditions of elevated temperature, as well as in hot climates, when concrete does not receive the necessary moisture care [3];

— plastic shrinkage – shrinkage of a freshly laid compacted concrete mixture. It develops within the first 3 hours from the moment of laying the foam concrete mixture and depends on the aggregate stability of the foam concrete mixture [9];

— carbonization shrinkage – occurs as a result of the reaction of portlandite contained in a cement stone with carbon dioxide to form calcium carbonate CaCO$_3$. The total volume of foam concrete is reduced, the structure is destroyed, and the strength is reduced. The carbonization of foam concrete is influenced by the concentration of CO$_2$ in the air, humidity and air temperature, type of cement, water-cement ratio, hardening conditions and maintenance.

The problem of controlling the processes of foam concretes production with low shrinkage is very relevant and is still not fully resolved [4-7, 10, 11].

The following technological methods have found their application to regulate the shrinkage of foam concrete, the setting time and the speed of hardening of binders.

— use of reinforcing fibers. Most researchers note [1, 4, 7, 12] that an effective solution to the problem is the use of various types of reinforcing fibers that can absorb tensile stresses throughout the entire volume of the product. Shrinkage reduction is achieved by introducing fiber into the composition of cellular concrete. An effective technique is polydisperse reinforcement, which involves the use of a combination of fibers with different characteristics. Shrinkage deformations of fiber-reinforced concrete depend on the elastic modulus of cellular concrete and fibers, as well as on the fraction of volume reinforcement, coefficient of volume reinforcement;

— the use of active mineral admixture. Ground quartz sand or other types of siliceous materials are used for autoclaved foam concrete: marshalie, tripoli, diatomite, flask, loess and others, as well as metallurgical granulated slags, fly ash of a power plant, including the use of aluminosilicate microspheres [13, 14, 15];

— the use of modifying additives. The most effective technological technique for regulating the shrinkage of foam concrete is the use of modifying additives, in particular hardening accelerators [4, 6, 16]. The introduction of hardening accelerator additives in the foam concrete mixture, even in small amounts, provides accelerated initial structure formation of the foam concrete mixture, thereby significantly reducing the shrinkage deformation of foam concrete. The most common and most effective hardening accelerators are chlorides and mixtures based on them.

The aim of this study is to establish patterns of influence of hardening accelerators on the properties of foam concrete mix and foam concrete.

2. Materials and methods

In carrying out experimental research were used raw materials that meet the requirements of national standards of Russia. As binders Portland cement of Topki Cement Factory (Kemerovo Region, Russia) CEM I 42.5H (Russian State Standard GOST 30515-2013) was used, sand of Kudrovskoe deposit of Tomsk Region (Russia) with fineness modulus 1.7 (Russian State Standards GOST 8736-2014 and GOST 26633-2012) and water (Russian State Standard GOST 23732-2011).
PB-Lux (Specifications 2481-004-59586231-2005) was chosen as foam agent based on the results of the evaluation of the quality of the foam agents [4].

The calcium chloride (Russian State Standard GOST 450–77 “Technical calcium chloride. Technical conditions”) and calcium oxalate were used as a hardening accelerators. Calcium oxalate is a salt of an alkaline-earth metal of calcium and organic dibasic oxalic acid. Hardening accelerators were introduced in the following dosage: calcium chloride 2%, calcium oxalate 0.5% by weight of cement.

Physical and mechanical properties of foam concrete were defined in accordance with Russian State Standards requirements: compressive strength (GOST 10180–2012); average density (GOST 12730.1-78). Plastic shrinkage and plastic strength were determined within the first three hours from the moment of foam concrete mixture placement into the mould according to methodology described in [4].

Compositions of foam concrete were selected in accordance with Russian Standard SN 277-80 “Instructions for the production of cellular concrete products” and given taking into account the actual average density of the concrete mix (Table 1) [4-6].

| Type of foam concrete | Components consumption | Average density grade |
|-----------------------|------------------------|-----------------------|
| Reference No.1        | cement, kg sand, kg water, l foam agent, l hardening accelerator, kg | D400 |
| With calcium oxalate 0.5% | 210 105 157.5 1.7 | - |
| Reference No.2        | cement, kg sand, kg water, l foam agent, l hardening accelerator, kg | D600 |
| With calcium chloride 2% | 280 140 210 1.5 | 5.6 |

Foam concrete mixture formation was performed in one stage using laboratory foam concrete mixer [4]. The molded foam concrete samples are marked and maintained under normal conditions at a temperature of 20±2°C for a day, after which they are released and placed in a normal hardening chamber, where they are stored for 7 and 28 days until testing at a temperature of 20±2°C and relative humidity of not less than 90%. Testing and evaluation of the quality of foam concrete was carried out according to Russian State Standard GOST 25485-89.

3. Results and discussions

Plastic strength is an important parameter of the rheological characteristics of the foam concrete mix. Inter-pore partitions should provide preserving the cellular structure when the elasticity of the surfactant films decreases so that it is insufficient to hold the gas phase. It is known from practice that the inter-pore partitions of foam mixtures acquire the ability to fix the geometry of the gas phase only after a sufficient number of viscous contacts between the particles of the solid phase are replaced by elastic ones. The time required for the formation of such contacts in cement-containing disperse systems is from 150 minutes or more [4]. Based on the foregoing, the test of plastic strength lasted 3 hours. The results of the effect of hardening accelerators on the plastic strength of the foam concrete mixture are presented in Figure 1.

As the results shown in Figure 1, foam concrete mixtures with additives in the initial stages of hardening have higher plastic strength values in comparison with foam concrete mixture without additives.

The plastic strength of foam concrete mixtures with additives is 2–3 times greater in comparison with the control composition after 3 hours of hardening. With the introduction of calcium oxalate in an amount of 0.5% by weight of cement leads to increase $R_{pl}$ from 128.2 to 418.7 Pa, and using calcium chloride in an amount of 2% by weight of cement leads to increase $R_{pl}$ from 256.4 to 535.1 Pa.
Based on the results presented in fig. 1 it is shown that the introduction of hardening accelerators into the foam concrete mixture allows it possible to accelerate the initial structure formation of foam concrete and increase the aggregative stability of foam concrete mixtures [4, 6, 8]. It can be concluded that a consequence of an increase in the aggregate stability of foam concrete structures from the beginning to the end of cement setting will be a decrease in the shrinkage deformations of the foam concrete mixture and foam concrete. In this regard, studies have been conducted on the effect of hardening accelerators on the shrinkage deformation of the foam concrete mixture.

Figure 2 shows the results of a study of the effect of additives on the plastic shrinkage ($\varepsilon_{pl}$) of foam concrete mixtures. It was found that the addition of hardening accelerators to the foam concrete mixture leads to decrease the plastic shrinkage by 47–65%. Using calcium chloride allows to decrease plastic shrinkage by 65% compare with the results of testing the foam concrete mixture without additives (reference No.2), using calcium oxalate - by 47%, compared with the results of testing the foam concrete without additives (reference No.1). The obtained data confirms the results of a study on the effect of hardening accelerators on the process of early structure formation of foam concrete. Accelerating this process, hardening accelerators stabilize the porous structure of the foam concrete mixture and thereby reduce the shrinkage deformation of the foam concrete mixture.
Since the properties of the foam concrete mixture determine the quality parameters of foam concrete, the following studies have been conducted on the effect of hardening accelerators on the properties of hardened foam concrete.

The main physical and mechanical properties of foam concrete are strength characteristics and density. The density and strength of foam concrete are closely related, the higher the density, the higher the strength. In Figure 3 presents the results of studies to determine the values of compressive strength and average density of foam concrete samples with and without hardening accelerators.

![Figure 3. The effect of hardening accelerators on the properties of foam concrete](image)

It is shown from Figure 3 that using calcium chloride in an amount of 2% by weight of cement allows to increase the compressive strength of foam concrete at 7 days age from 0.77 to 0.98 MPa. The introduction of calcium oxalate in an amount of 0.5% by weight of cement leads to increase the compressive strength of foam concrete by 51.6% in comparison with the reference No.1 samples at 28 days age, the density varies slightly. In the same terms, with the introduction of calcium chloride in an amount of 2% by weight of cement, the compressive strength of foam concrete increases by 50% compared with the reference No.2 samples, while the density also changes slightly.

Calcium chloride increases the solubility of free lime released by cement, and accelerates the hydration of clinker minerals. As a result, the hydration of cement increases in the initial period, due to that the formation of gel increases, and the early strength of foam concrete increases.

Calcium oxalate increases the strength of concrete by accelerating the hydration of the main strength carrier - tricalcium silicate.

4. Conclusion
An effective heat-insulating and structural-heat-insulating material is foam concrete. The mechanism for reducing shrinkage deformations of foam concrete and foam concrete mixture is based on the addition of hardening accelerators, which reduce shrinkage and cracking due to the accelerated process of initial structure formation of natural hardening foam concrete.

According to the results of the study, it was found that:
1. The introduction of calcium chloride in an amount of 2% by weight of cement into the foam concrete mixture leads to increase the plastic strength of the foam concrete mixture after three hours of hardening from 256.4 to 535.1 Pa, while the plastic shrinkage decreases by 64.8%, compared to test
results of foam concrete mixture without additives. When calcium oxalate is introduced into the foam concrete mixture in an amount of 0.5% by weight of cement, the plastic strength of the foam concrete mixture after three hours of hardening increases from 128.2 to 418.7 Pa, while the plastic shrinkage decreases by 47.7%, compared to reference No.2.

2. The introduction of hardening accelerators leads to an increase in the compressive strength of foam concrete in the early stages of hardening. The introduction of calcium oxalate in an amount of 0.5% by weight of cement allows to increase the compressive strength at 28 days age from 0.31 to 0.47 MPa (by 51.6%), compared with the reference No.1, while the average the density slightly decreases from 341 to 334 kg/m$^3$. The introduction of calcium chloride in an amount of 2% by weight of cement leads to increase the compressive strength of the foam concrete from 0.96 to 1.44 MPa (by 50%) compared with the reference No.2, while the density increased from 525 to 542 kg/m$^3$.

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