Research of structuring processes of non-autoclave foam concrete with introduction of mineral additives

N Mashkin¹, E Bartenjeva²

¹Department of Engineering Problems of Ecology, Novosibirsk State Technical University, 20, Prospekt K. Marksa, Novosibirsk 630073, Russia
²Department of Building Materials, Standardization and Certification, Novosibirsk State University of Architecture and Civil Engineering (Sibstrin), 113, Leningradskaya street, Novosibirsk 630008, Russia

E-mail: ek.bartenjeva@yandex.ru

Abstract. The article is concerned on the ways of improving the quality of non-autoclaved foam concrete. The effective method is the use of fibrous additives that provide reinforcement of the material structure. It is noted that the use of basalt and glass fiber, fine additives of wollastonite and diopside increases the aggregate stability of the foam concrete mixture. In this case greater extent is when introducing mineral additives. This reduces the density of the material to D300 and D400 as well as the thermal conductivity coefficient to 0.069-0.097 W/(m·°C). It was found that wollastonite and diopside additives in comparison with fiber one provide greater adhesion to cement stone. Introducing the proposed additives reduces the plastic shrinkage of foam concrete samples by 15.6-20.8% with the introduction of mineral additives and 59.2-61% with the introduction of fiber. The shrinkage on drying is reduced with the introduction of mineral additives in foam concrete by 23-35% and with the introduction of fiber shrinkage reduction is not observed. The use of mineral additives, such as wollastonite and diopside, allows improving the quality of foam concrete products due to increased air entrainment, the formation of optimal porosity, more complete hydration of the minerals of cement stone and a better adhesion of additives with cement stone.

1. Introduction

Western Siberia is a region between the Urals and the Yenisei valley, which extends from South to North from the steppes of Kazakhstan and the Altai mountains to the Kara sea and its bays. In Western Siberia there are the largest oil and gas provinces in the country, the most fertile lands in Siberia, important centers of metallurgical and chemical industry. The largest cities in Western Siberia are Novosibirsk, Omsk, Tyumen, Barnaul, Novokuznetsk, Tomsk and Kemerovo. The average temperature here in varies from -15 °C (South) to -40 °C (North). The average temperature in July is from +5 °C (in the North) to +20 °C (in the South). In the North of Western Siberia winter lasts about nine months, in the center - about seven months and five months in the South [1-3].

Thus, the actual task for Western Siberia is to increase the thermal resistance of building enclosing constructions. The thermal foam concrete construction of buildings can be used as a solution [4-8], as they increase the thermal protection functions of buildings, provide comfortable indoor climate, can improve the quality and increase the pace of construction.
It is known that one of the determining factors affecting the quality, performance characteristics of foam concrete is the resistance of foam and foam concrete mixture [9-10]. One of the ways to improve its stability is the introduction of substances that increase the viscosity of the foam (gelatin, CMC, liquid glass) [11-12]. The foam system stabilization can be achieved when introducing carbonate materials [13] and by regulating the water temperature [14].

A number of authors suggest that it is possible to improve the quality of non-autoclave foam concrete by accelerating the hardening of the cement stone [9, 15-17]. Some researchers suggest the use of mechanical activation; others use additives that accelerate hardening.

There are known scientific works in which it is proposed to increase the stability of the foam structure by modifying the foam with a fiber. Fibers create a reinforcing spatial framework preventing the appearance of shrinkage cracks in the hardened foam concrete. Basalt fiber, polypropylene, glass, cellulose filler based on waste paper, coconut fibers and others are used as reinforcement fibers [17-22].

2. Characteristics of reinforcing components

Glass and basalt fiber were used as reinforcing components. Glass chopped fiber of the EU brand 13-12-4C (Armplast) with 12.3 mm fiber length and a diameter of 13.7 microns, chemical composition, wt. %: SiO₂ — 60,7, Al₂O₃ – 0,1, ZrO₂ – 20,1, Fe₂O₃ – 2,6, Na₂O – 14,1, K₂O – 2,4. Basalt fiber with a fiber length of 12 mm, diameter of 12 mm, chemical composition, wt. %: SiO₂ — 50,5, Al₂O₃ – 18,0, CaO – 8,5, Fe₂O₃ – 12,0, MgO – 4,5, Na₂O – 3,5, K₂O – 3,0.

Mineral additives of wollastonite and diopside were also used. Wollastonite was used in the Altai Deposit with the following chemical composition, by weight. %: SiO₂ – 46,1; Al₂O₃ – 2,93; Fe₂O₃ – 4,44; CaO – 45,12; MgO – 0,9. The true density of wollastonite is 2455 kg/m³, the specific surface area is 90 m²/kg. Figure 1 shows the type of wollastonite particles. According to the micrograph it is seen that in great extent the additive is represented by elongated particles, the maximum length of which is 4-6 mm, the minimum particle size is 150-200 μm.

The diopside of the Slyudyanskoje field with a true density of 2778 kg/m³ and a specific surface of 100 m²/kg was investigated. The chemical composition of the diopside is represented by the following elements, wt. %: CaO – 25,03, MgO — 20,01; SiO₂ — 51,33, Al₂O₃ – 1,88; Fe₂O₃ – 0,84; MgO – 20,01; K₂O –0,17. The irregular shape of a particle with a particle size of 400-500×50-400 μm is encountered in diopside (Figure 2). Unevenness, roughness, and sharp angles can be seen on the surface. This should ensure better adhesion to the cement stone.

Wollastonite and diopside were injected into the foam or mortar mixture, the best result was obtained for samples of foam concrete with an additive introduced into the cement-ash solution.
3. Experimental Method

3.1. Materials
The study used Portland cement PC 500 D0 (Iskitim cement plant), acidic fly-ash (CHP-5, Novosibirsk), water, foaming agent Foamcem. The concentration of the foam solution is 2.5%. The foam concrete composition was calculated for the density 500 kg/m³.

3.2. Procedure
To produce foam concrete samples, a foam was prepared for 6.5 minutes in a foam generator. Cement-ash mortar mixture was prepared separately: Portland cement was mixed with fly ash and mineral additive for 2 minutes, after that water was introduced into mixture. In case of fibrous additives, they were first introduced into the water for mixing. After that, the mixture was prepared in a turbulent mixer for 3-4 minutes. Then, the resulting foam was added into the resulting mortar mixture, followed by mixing of the components for 2 minutes. The resulting mixture was placed in pre-prepared and lubricated molds and stood for 24 hours, followed by their decking. After 28 days of hardening under normal conditions, the samples were tested.

3.3. Experimental Test
Preliminary experiments were conducted, the optimum amount of the additive was established as a result: for the fiber it was 0.3% of the cement mass, and for mineral additives – 1%.

For samples of foam concrete with additives, the coefficient of foam stability in the mortar mixture was determined. The coefficient of foam stability in the mortar mixture reflects not only the compatibility of the technical foam with the medium of the hardening mortar, but also shows the volume fraction of the foam use in porous solution preparation.

In accordance with normative documents, the compressive strength (GOST 10180), the average density (GOST 12730.1), the thermal conductivity in dry state (GOST 30256), and the plastic shrinkage [21] and upon drying one (GOST 25485) were determined.

Determination of particle size and shape, structural changes of foam samples were studied with the use of a scanning electron microscope HITACHI TM-1000 (Institute of Solid State Chemistry and Mechanochemistry, SB RAS). The survey was carried out in low vacuum mode with 30 nm resolution.

The mineral composition of foam concrete samples with various additives was determined on a diffractometer D8 Advance with CuKα-radiation when registering with a one-dimensional detector Lynx-Eye (Institute of Solid State Chemistry and Mechanochemistry SB RAS).

4. Results
Due to the introduction of the test additives, the aggregate stability of the foam concrete mixture increases. The coefficient of foam stability in the mortar mixture is higher when introducing mineral additives in comparison with fiber one [22].

Wollastonite Ca₃[Si₂O₇] and diopside CaMg[Si₂O₆] are calcium silicates, i.e. natural analogues of clinker minerals, that can provide a stronger adhesion of new formations of hardening cement paste to the surface of such silicate additives.

Figures 3, 4 show the glass and basalt fibers respectively, after the destruction of the foam concrete. It can be noted that there are practically no hydrated cement stone products on the surface. Thus, the foam destruction occurred along the boundary of the fiber and cement stone, indicating a poor adhesion between the additive and the fiber.
Diopside addition (Figure 5) is tightly surrounded by new cement formation, which shows good adhesion with cement stone minerals. On the wollastonite particle (Figure 6) there is a visible formation of cement stone hardening products, which may also indicate a better adhesion of the mineral to the cement stone.

According to the results of X-ray diffraction analysis in samples with wollastonite additive, the intensity of the diffraction reflection of calcium hydroxide (49.20 nm) is higher than in the control samples, that is possible with a greater extent of cement hydration.

Due to the increased aggregative stability of the foam concrete mixture with fiber additives, the average density is reduced to 387 kg/m³ for samples with basalt fiber and to 394 kg/m³ with glass one, up to 274 kg/m³ with diopside and to 375 kg/m³ with wollastonite. Thermal conductivity of the material also decreases (Table 1). Micro porosity of foam concrete samples increases with the addition of wollastonite and basaltic fiber and provides a stronger reduction in the thermal conductivity coefficient.

| Parameter                  | Type of an additive |
|----------------------------|---------------------|
| Density (kg/m³)            | Control  Diopside  Fiberglass Basalt fiber Wollastonite |
| 547                        | 274  394  387  375 |
| Compressive strength (MPa) | 1.22  0.57  0.67  1.05  1.00 |
| Coefficients of thermal conductivity (W/(m°C)) | 0.122  0.069  0.097  0.073  0.070 |
| Plastic shrinkage (mm/m)   | 7.20  6.08  2.94  2.81  5.70 |
| Shrinkage on drying (mm/m) | 2.6   2.0   3.1   2.8   1.7 |
Due to better adhesion of mineral additives with new formations of cement stone shrinkage on drying decreases of the foam concrete samples. The plastic shrinkage is more influenced by synthetic fiber additives. Perhaps, it depends on their ability to form a spatial framework that has a positive effect on the resistance of the foam concrete mixture at the initial time of hardening.

5. Conclusion

Thus, the introduction of mineral and fibrous additives makes it possible to increase the aggregative stability of foam concrete mixes. Due to it the density and thermal conductivity coefficient of the foam concrete are reduced. Mineral additives provide better adhesion to cement stone due to their affinity with clinker minerals. At the same time, the parameters of shrinkage deformations of the obtained foam concrete are also improved.

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