Thermal highly porous insulation materials made of mineral raw materials

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Abstract. The main objective of the study is to create insulating foam based on modified mineral binders with rapid hardening. The results of experimental studies of the composition and properties of insulating foam on the basis of rapidly hardening Portland cement (PC) and gypsum binder composite are presented in the article. The article proposes technological methods of production of insulating foamed concrete and its placement to the permanent shuttering wall enclosures in monolithic-frame construction and individual energy-efficient residential buildings, thus reducing foam shrinkage and improving crack-resistance.

1. Introduction

It is known that in modern conditions, the role of inorganic natural materials in the manufacture of building materials has priority. Particularly suitable for the cold climate in most regions of Russia are insulating materials which are produced using low-power technology [1] including cellular concrete and foamed concrete.

Research in the area of foamed concrete is aimed at creating new types of synthetic and protein foaming agents, new multicomponent compositions with various mineral and chemical additives, as well as creating dry mixtures for producing foamed concrete using mechanical activation of raw materials, etc. However, the results of such studies are not always acceptable for construction in the northern regions remote from industrial centers [2].

Therefore, relevant issue for each region is development of optimal compositions for insulating foamed concrete depending on the availability of source components and raw materials in accordance with their technical and economic efficiency.

2. Materials and methods

The basic component of the activated binding mixture used for production of insulating foamed concrete are burnt rocks, characterized by the following chemical composition, % wt.: \( \text{SiO}_2 \) – 65,05; \( \text{TiO}_2 \) – 0,70; \( \text{Al}_2\text{O}_3 \) – 16,62; \( \text{Fe}_2\text{O}_3 \) – 6,06; \( \text{FeO} \) < 0,25; \( \text{MnO} \) – 0,07; \( \text{MgO} \) – 1,80; \( \text{CaO} \) – 2,45; \( \text{K}_2\text{O} \) – 2,52; \( \text{Na}_2\text{O} \) – 3,16; \( \text{P}_2\text{O}_5 \) – 0,18; \( \text{SO}_3 \) – 0,65; \( \text{CO}_2 \) < 0,20; ignition losses – 0,28. Inhomogeneity of burnt rocks properties is explained by the different degree of burning. Activity of burning rocks increases with increasing fineness of grinding. Powdered supplement of the burning breed completely passed through sieve № 008, its specific surface area (\( S_{\text{sp}} \)) is 350-400 m\(^2\)/kg. In the course of earlier studies [3] it was found that burnt rocks are typical representatives of the group of hydraulic
substances of glinite kind. Hardening of binders based on burned rocks should be regarded as processes in polymineral system the $\text{Al}_2\text{O}_3 – \text{CaO} – \text{SiO}_2 – \text{Fe}_2\text{O}_3 – \text{H}_2\text{O}$.

In the selection of composition of foamed concrete the following materials were used: Portland cement (PC) of "Yakuttsement" company, characterized by the following chemical composition, wt%: $\text{SiO}_2 – 21.16; \text{Al}_2\text{O}_3 – 5.45; \text{Fe}_2\text{O}_3 – 4.72; \text{CaO} – 64.85; \text{MgO} – 2.71; \text{R}_2\text{O} – 0.75; \text{CaO}_{\text{free}} – 0.15$; other material was gypsum binder matter (GBM), made of gypsum stone of Olyokminskiy and Dapparayskiy deposits. Content in the gypsum rock $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ is: Olekminsky deposit – 80.80% (III grade); Dapparayskiy deposit – 93.96% (I grade).

As silica component river sand was used, satisfying the requirements of GOST 8736-93 "Sand for construction works. TU" (Russian State Standard).

As the blowing agent synthetic foaming agent brand PB-2000 (Russia) was used for obtaining foam concrete by equipment "Stromros" and proteinaceous foaming agent "FOAMSEM" (Italy); and for obtaining foamed concrete by classical way the equipment “SOVBI” was used.

Standard methods were used to determine the physical and mechanical properties of binders and concrete with the use of modern techniques and equipment: XRD and DTA obtained materials carried on the X-SRS-3400 spectrometer and diffractometer D8 Discover with GADDS for phase analysis; study on thermal conductivity was carried out on HFM 436 Lambda on samples with dimensions 300x300x100 (300) mm.

In the selection of foam formulations mathematical planning of the experiment was used. Multivariate polynomial models allow us to solve the vast majority of engineering problems in materials science and technology, so these ES models should be regarded as basic to practice of engineering in the industry.

### 3. Insulating foam on the basis of rapidly hardening Portland cement

To solve the problem we have optimized composition of Portland cement, modified by the introduction of complex additives based on gypsum and burnt rocks (rapidly hardening Portland cement).

Acceleration of paste hardening is shown with decreasing content of burned rock in the complex additive, which corresponds to increased content of gypsum binder matter (GBM). It should also be noted that timing of setting binder is hardly affected by the change in flow of complex additive itself. Thus, start of setting can be controlled within 25...60 min, and the end of setting time - 40...140 min.

#### Table 1. Comparative characteristics of thermal insulation foamed concrete of D300 grade at various binders.

| Heat resistant foamed concrete | Composition, wt. % | Duration, h | Average strength on compression, MPa |
|-------------------------------|---------------------|------------|---------------------------------|
| On PC 400 - DO                | Portland cement 100 | gypsum 5.5 | burned rocks 4.5 | start of setting $\geq 0.75$–1.75 | end of setting 4.5–6 | 0.51 |
| On PC-B                       | 90                  |            |                    | 0.5                        | 1.25              | 0.56 |

Optimum compositions of PC-B have values of compressive strength after 28 days of hardening in normal conditions in the range 15...17 MPa and the linear expansion of 0.7%, containing 10% of integrated additive content in its composition as well as burning breed within 50...60% by weight.

Design of formulations of grades D300 and D500 foamed concrete was made on the basis of produced rapidly hardening cement. According to the results, the graphs of dependence of the tensile strength of foamed concrete on binder composition (Figure 1) were designed.

Analysis of the graphs showed that the highest compressive strength was achieved when using PC-B of 10/45 in both cases, i.e. at flow rate of 90% of Portland cement, 4.5% of burnt rocks and 5.5% of gypsum binder in the total mass of the composite binder. In this case setting and hardening time of foamed concrete mix is significantly reduced and, strength characteristics increase (up to 10%).
compared to foamed concrete on conventional Portland cement PC 400-D0 (Table 1). According to the test results on samples of air shrinkage in bench and field conditions, obtained foamed concrete relates to dimensionally stable cellular concrete.

Figure 1. Dependence of the compressive strength of foamed concrete samples D 300 (28 days) and D500 (14 days) on the composition of rapidly hardening Portland cement PC-B.

4. Insulating foamed concrete based on composite gypsum binders

Optimum composition of composite gypsum binder with the strength of brand M200 using burnt rocks sifted through a sieve number 008 (with surface area of 350 m²/kg), has starting and ending points of setting 7 and 7.5 min, respectively, compressive strength after 2 h. after mixing with water 4 MPa after 28 days – 20.5 MPa and 0.75 softening coefficient (Figure 3).

Figure 2. Dependence of the compressive strength of foamed gypsum concrete samples D400 aged 28 days on the flow of materials.

To confirm the phase composition of the foamed concrete samples based on PC-B and composite gypsum binder (CGB) X-ray analysis of the sample at the age of 3 years was carried out. Analyzing X-ray shown in Fig. 3, it must be concluded that the main cementing substance of the samples on the PC-B are low base calcium hydro silicates CSH (B) (d = 9.91; 7.59; 4.96; 3.79; 3.01; 2.67; 2.21; 2.07; 1.89; 1.63 \times 10^{-10} \text{m}) and the dihydrate gypsum CaSO₄ \cdot 2H₂O (d = 7.59; 4.28; 3.06; 2.87 \cdot 10^{-10} \text{m}).

For CGB the main cementing substance of the samples is gypsum dihydrate CaSO₄ \cdot 2H₂O (d = 7.59; 4.28; 3.79; 3.06; 2.87 \cdot 10^{-10} \text{m}).

Radiographs of both binders samples contain lines of hydrosulfoaluminate of highly basic forms of calcium - ettringite 3CaO \cdot Al₂O₃ \cdot 3CaSO₄ \cdot 32H₂O (d = 9.71; 5.60; 4.96; 4.69; 3.87; 2.78; 2.59; 2.22; 1.66 \cdot 10^{-10} \text{m}), low basic calcium hydro silicates CSH (B) (d = 12.52; 9.91; 4.90; 3.07; 2.80; 1.83 \times 10^{-10} \text{m}), calcium carbonate CaCO₃ (d = 3.00; 2.49; 2.28; 2.08; 1.91; 1.87 \cdot 10^{-10} \text{m}), silica SiO₂ (d = 4.26; 3.34; 2.14; 1.99; 1.81; 1.53 \cdot 10^{-10} \text{m}), as well as traces of hemihydrate gypsum CaSO₄ \cdot 0.5 H₂O (d = 6.01; 4.35; 3.00; 2.80 \cdot 10^{-10} \text{m}) and non-hydrated portland cement minerals (d = 2.3;
2.77 \cdot 10^{-10} \text{ m}). Electron micrographs show that increase of strength characteristics of foam is associated with decrease in porosity of interporous partitions.

**Figure 3.** X-Ray pattern of the samples on the PC-B (aged 3 years) and CGB (aged 2 years).

5. Conclusion
For dimensionally stable insulating foam of D300 and D500 grades, maximum compressive strength of 0.43 MPa and 0.51, respectively (100% cement – 0.35 and 0.43 MPa, respectively) is achieved using the initial composition containing 90% cement, 5.5% and 4.5% gypsum burnt rocks in the total mass of dry mix, that can accelerate the process of foamed concrete mix hardening 2-3 times and provide high-quality thermal insulation layer of permanent formwork wailing [4].

Introduction of additives consisting of Portland cement and fine ground burnt rock M400 with a specific surface of 350 m/kg\(^2\) to the CGB allows to adjust the start and end time of paste setting (7.5 and 7 minutes, respectively), values of strength and water resistance (softening rate 0.75); compositions of CGB containing 10 to 50% additives, which include 10 to 40% of burnt rock have maximum strength and values of compressive strength 21.0 and 20.5 MPa respectively.

Technology of construction [4], as well as construction of wall fences [5] in the cast-frame construction and individual construction were developed and implemented to reduce costs and speed up construction time, improve the energy efficiency of buildings operated in cold climate of Yakutia with high quality of construction and installation works.

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