Technology of foam concrete production with ultradispersed quartz waste

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Abstract. The article presents a technology for producing foam concrete using activated quartz waste. The waste is an ultrafine filler in the cement stone that builds pore-forming walls and generates a structure with minimal pores (with a diameter down to 50 microns) and walls with similar cross-section. The average density of such foam concrete is 500 kg/m³ and the total porosity equals 69-76%. The specimens demonstrate increased strength and reduced thermal conductivity. The use of the ultrafine filler in foam concrete reduces cement consumption by 10%, increases the density of the cement stone by 4%, augments the strength of the foam concrete by 10% and reduces its thermal conductivity by 8%. The results of the tests approve increased operational, physical and mechanical properties of such foam concrete.

1. Introduction
Foam concrete is a solid material from cement stone forming walls of evenly distributed pores (macropores). The capillary and gel pores (micropores) are evenly distributed in the cement stone. The macroporosity and microporosity of foam concrete depend on the type and properties of the foam-generating agent, granulometric composition of the filler, chemical additives, preparation technology, solid-to-liquid ratio, water-to-cement ratio and temperature of the mixture.

The subject of the study is the effect of activated quartz waste as ultrafine filler on the structure of the pore walls in foamed concrete. The study shows that the strength properties of foamed concrete increase due to the discrete reinforcement of the pore walls and, as a consequence, reduces cement consumption.

Hydration of cement determines the properties of cement-stone pore walls. Various physical and chemical processes are responsible for the formation of high-strength cement stone. A crucially important characteristic is strong adhesion of quartz particles to cement formations conditioned by secondary bonding with quartz grains formed from hydrates recrystallized from plates. These particles give rise to zones of crystalized inclusions. The filler should actively react with Ca(OH)₂ and other clinker hydration products. Its surface should have maximum possible compatibility with the structure of crystallizing hydrates, serving as a substrate for them [1–4].

The aim of the study was to improve a technology of foam concrete production using activated quartz waste as an ultrafine filler of the cement stone structure forming pore walls of the foam. Such technology can enable an evenly distributed pore structure with the same cross-section of pore walls, increase strength and reduce thermal conductivity of foam concrete [5].

2. Research methods
The structure of the specimens was determined using a REM-100U scanning electron microscope (Russia). The specific surface and average particle size were determined on PSKh-12 instrument.
(Russia). The heat conductivity of the specimens was measured by the method of stationary heat flux using ITP-MG4 device (Russia). The porosity was measured by mercury porosimetry on a Porosimeter 2000 pore analyzer (Fision Instruments, Spain).

3. Experimental
To prepare the mortar for foam concrete production, quartz waste from production of ultrapure quartz concentrate (LLC "Polar Quartz", Russia) was used. It consisted of secondary waste after grit magnetic separation (25–26 μm) and powder classification (6–7 μm), and dust from an on-site suction system (3–6 μm).

To prepare the experimental concrete specimens, the following technological scheme was used.
1. The quartz waste was fed into a centrifugal disk mill for activation.
2. The ultrafine quartz filler (10 wt%) and cement (TsEM II / A-Sh 42.5N) with common granulated blast furnace slag were dosed and mixed, and then fed into a feed hopper by a pneumatic transporter.
3. A frothing agent and water at a temperature of 20–25 °C were fed to a foam generator. The frothing time was 5–6 minutes.
4. The foam was mixed with the mortar in a mixer for 3–4 minutes;
5. Then, the foam was poured into molds, and cured for 3–4 hours at a temperature of 20 °C.
6. Then, the specimens were subjected to hygrothermal treatment in an autoclave at 12 atm as per the following heating regime: gradual temperature increase up to 80 °C over 4 hours; isothermal soaking at 80 °C for 6 hours; and gradual temperature decrease down to 20 °C over 4 hours.

The flowchart of foam concrete specimen preparation is depicted in Figure 1. The values of specific surface area ($S_{sp}$) and the average size (d) of quartz waste particles after dry activation are presented in Table 1.

| Waste type                           | Specific surface area [cm$^2$/g] | Particle size [μm] |
|--------------------------------------|---------------------------------|-------------------|
| Grit magnetic separation waste       | 1575–1951                       | 17–20             |
| Powder classification waste          | 3321–4815                       | 4–7               |
| Dust from on-site suction system     | 5579–9547                       | 2–4               |

Table 1. Specific surface area and average quartz particle size.

The proposed technology of foam concrete provides an evenly distributed closed-pore structure with pore walls having similar cross-section. The walls are reinforced by ultrafine quartz filler: needle-like crystals penetrate the pore space and strengthen the structure of the foam concrete. The properties...
of the specimen are affected by pore volume and pore dimensions: the total pore volume in the pore walls of the specimens was 0.04 cm³/g with a pore diameter of 0.061 μm, while the total pore volume of the specimens was 0.75 cm³/g with a pore diameter of 1–50 μm.

Figures 2 and 3 illustrate the microstructure of pore space and pore walls of the specimens, respectively.

![Figure 2](image1.jpg)

**Figure 2.** Microstructure of pore space of foam concrete.

![Figure 3](image2.jpg)

**Figure 3.** Microstructures of pore walls of foam concrete.

Evidently from the figures, needle-like ettringite crystals penetrate calcium hydrosilicate particles, which contributes to the strengthening of the microstructure and augments the characteristics of the foam concrete specimens as a whole.

The main physical and technological properties of foam concrete specimens with addition of activated ultrafine quartz filler are given in Table 2.
Table 2. Physical and technological characteristics of experimental foam concrete specimens.

| Characteristic                                                                 | Value                          |
|-------------------------------------------------------------------------------|-------------------------------|
| Concrete grade in terms of average density                                   | D400                          |
| Heat conductivity coefficient [W/(m K)]:                                      |                               |
| • grit magnetic separation waste                                             | 0.113                         |
| • powder classification waste                                                | 0.119                         |
| • dust from on-site suction system                                            | 0.122                         |
| Water vapor transmission rate [kg/(m h Pa)]                                  | 0.18                          |
| Sorption humidity [%] (at relative humidity of 75%)                          | less than 7–9                 |
| Compression strength [MPa]:                                                  |                               |
| • grit magnetic separation waste                                             | 1.57                          |
| • powder classification waste                                                | 1.21                          |
| • dust from on-site suction system                                            | 0.98                          |

4. Conclusion
Following the results of the research, the addition of an ultrafine filler (activated secondary quartz waste after grit magnetic separation and powder classification, and dust from on-site suction system) to the foam cement mortar leads to the quartz particles penetrating the structure of pore walls, which saves up to 10% of cement, increases the cement stone density by 4%, improves the foamed concrete of by 10% and lowers the thermal conductivity coefficient by 8%.

The technology of foam concrete with the use of activated quartz waste allows creating a structure with a pore diameter of up to 50 microns, average density of foamed concrete of 500 kg/m³ and total porosity of the foam concrete specimens of 69-76%. It increases strength and reduces thermal conductivity of the concrete. The share of the pore volume in the cement stone pore walls is less than 0.4% of the total pore volume and varies with the cement hydration degree. The increased pore wall strength is due to discrete reinforcement by ultrafine quartz waste filler.

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