The influence of quartz waste addition on the porosity of cement stone

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Abstract. The article examines the effect of a nanofiller addition, produced from activated quartz waste, on general porosity of cement stone. It contributes to the uniform distribution of micropores and reduction of the cement stone porosity. This improves the physical and mechanical properties of the cement stone. The porosity of the cement stone reduces by 17%, while its density and strength increases.

1. Introduction
The structure of the cement stone is formed in the process of complex hydration interaction of solid, liquid and gas phases. The curing stages are bound with the nucleation and formation of crystalline phases.

Currently, the technology of cement stone is inconceivable without implementation of special-purpose modifiers that affect deeper structure-formation mechanisms. These are so-called nano-additives and nano-modifiers, which implementation should be reasonable and targeted, i.e. scientifically justified.

This article considers the effect of quartz waste used as a nanofiller to mineral-binder cement stone on the porosity of the stone, which is a modern solution regarding the physicomechanical properties of the end product and saving of cement.

The introduction of the nanoparticles causes generation of an additional interface, while the particles themselves demonstrate quantum-mechanical features. Physical contacts of the coagulation structure of the cement gel with nanofillers facilitate migration of atoms and emphasize the attraction forces between them, which assists the self-organization of cluster structures. Figure 1 presents the main physical specificities of nanomaterials [1-2].

The purpose is to study the effect of quartz waste (with a particle size of 26 µm and specific surface of 856 cm²/g) used as a nanofiller to mineral-binder cement stone on the porosity and strength of the stone.

2. Research methods
The specific surface and average size of the particles were determined on a PSKh-12 instrument (Russia). The structure of the specimens was determined using a REM-100U scanning electron microscope (Russia). The specimen mass was determined on a GOSMETR VLTE-150 device. The compression strength of the specimens was determined on a MATEST device with a digital module for specimen compression. The dimensions and distribution of pores in the specimens were measured by mercury porosimetry on a Quantachrome PoreMaster 33 porosity meter.
3. Experimental
The experiments studied the porous structure of the cement stone with activated quartz-waste filler that was uniformly distributed in the structure of the cement stone [3].

The technological procedure of mortar preparation with addition of ultradispersed quartz waste includes the following actions.

1. Quartz waste after magnet separation of grits (with a particle size of 26 µm and specific surface of 856 cm²/g) left from production of extra pure quartz concentrate were fed into continuous rotary mill for grinding (dry activation), which yielded the filler.

2. The filler in the amount of 10 wt% of cement and cement (TsEM II/A-Sh 42.5N) with an addition of granulated blast-furnace slag (general-construction grade) were dosed, mixed and pneumatically fed into a feed hopper.

3. The cement with filler and water with a temperature of 20–25 °C were dosed into the mixer and mixed for 5–6 minutes.

4. The ready concrete mixture was poured into molds and cured at 20–25 °C for 28 days.

The characteristics of ultrapure quartz concentrate (LLC "Polar Quartz", Russia) are presented in Table 1.

| Waste type: secondary waste after grit magnetic separation | Value       |
|----------------------------------------------------------|-------------|
| Powder density                                           | 2.65 (g/cm³) |
| Powder sample weight                                     | 8.83 (g)    |
| Powder layer height                                      | 12.9 (mm)   |
| Specific surface                                         | 856 (cm²/g) |
| Average particle size                                    | 26 (µm)     |
| Absolute error (of n > 3 observations):                  |             |
| - specific surface                                       | ± 17.8 (cm²/g) |
| - average particle size                                  | ± 0.7 (µm)  |
The specific surface area ($S_{sp}$) and the average size ($d$) of quartz waste particles after dry activation are presented in Table 2.

### Table 2. Specific surface area and average quartz particle size.

| Waste type                                | Experiments | Specific surface area, cm$^2$/g | Particle size, μm |
|-------------------------------------------|-------------|----------------------------------|-------------------|
| Grit magnetic separation waste            |             | 1570–1950                        | 15–23             |

The compression strength was determined for the specimens after 28 days of curing. The specimens were prepared from cement dough of normal density with a water demand of cement of 100 ml per 400 grams. The compression strength of the cement stone specimens without quartz waste was 56.6–61.1 MPa. That of cement stone with quartz waste after grit magnetic separation amounted to 65.4–71.3 MPa.

The structure of the specimens was studied by a scanning electron microscope (Figure 2). It revealed needle-like crystals and their agglomerates which are characteristic of ettringite (calcium hydrosulfosilicate). The prismatic crystals testify to the presence of alite; while the rounded crystals speak of the presence of belite. The crystallizational contacts form a peculiar rigid frame consisting of fibrous (needle-like) crystals that penetrate the porous space of the cement stone, which facilitates its strengthening and increases its compression strength.

### 4. Results

Characteristics of the porous structure of cement stone samples according to mercury porometry (Quanctochrome PoreMaster 33):
- total pore volume of cement stone specimens without quartz waste was 0.046 cm$^3$/g with a diameter of 48.1 nm;
- total pore volume of cement stone specimens with activated quartz waste (after magnet separation of grits with a particle size of 26 μm and specific surface of 856 cm$^2$/g) was 0.037 cm$^3$/g with a diameter of 28.47 nm.

The characteristics of the porous structure of cement stone are presented in Table 3.

### Table 3. Characteristics of cement stone porous structure

| Cement stone                   | Calculated porosity [%] | Mercury porosimetry results |          |          |          |          |
|-------------------------------|-------------------------|-----------------------------|----------|----------|----------|----------|
|                               |                         | Total pore volume [cm$^3$/g]| Mesopore volume [cm$^3$/g]| Macro-pore volume [cm$^3$/g]| Average pore radius [nm] |
| without quartz waste          | 6.0                     | 0.046                        | -        | 0.045    | 24       |
Table 1

| Material          | 4.6 | 0.037 | 0.011 | 0.033 | 14 |
|-------------------|-----|-------|-------|-------|----|

Figure 2 illustrates the microstructure of foam concrete.

![Figure 2. Microstructure of cement stone.](image)

5. Conclusion

Thus, the use of activated quartz waste (activated secondary quartz waste after magnetic separation of grits) as a nanofiller to cement stone based on a mineral binder, contributes to the uniform distribution of micropores, while the porosity of cement stone reduces by 17%, the physical and mechanical properties of cement stone improve, the density of cement stone increases by 6%, the strength of cement stone increases by 8% and the saving of cement reaches 10%. The reliability of the obtained results is confirmed by the agreement of experimental and calculated data.

References

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