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A selection of compositions of high strength and low thermal conductive energy efficient concretes with local materials

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Abstract: In the world, inert materials are used to obtain high-strength concrete, the volume weight of which is quite large. We cannot get concrete with low thermal conductivity from such inert materials. Therefore, in order to obtain high-strength, environmentally friendly and energy--efficient concrete, it was necessary to investigate local inert materials. The subject of research is natural zeolite and recycled ceramic waste, as well as polystyrene as an additive and micro-silica in cement mass to achieve penetrating waterproofing. The mentioned materials are obtained in Georgia in sufficient quantity, which allows us to produce energy-efficient concrete of high strength, low thermal conductivity, as well as sound and waterproofing. It is safe for both people and the environment. The correct mix will be provided by materials found in the local market, and the desired and low energy efficiency ensures the production of an environmentally friendly concrete.

Keywords: energy-efficient concrete, natural zeolite, inert materials

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Introduction

The composition of concrete according to the given characteristics (following from the conditions of its operation) is determined according to the following scheme (Nadiradze, 2009):

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- selection of concrete parameters (grade of acceptable concrete, grade and composition of cement, characteristics of aggregates) (Othman et al., 2021; Telloli et al., 2021);
- clarification of the characteristics of the selected materials; calculation of the necessary materials for 1 m^3 concrete (Nadeljkovic et al., 2022);
- compiling a test laboratory composition with its further changes (as needed);
- after clarification of the composition of concrete, clarification of the cost of materials required for the production of 1 m^3 concrete (Turdzeladze, 2017);
- formation and testing of samples to be tested.

When choosing fillers, binders and active additives, it should be taken into account that the bulk density of concrete does not exceed 1800 kg/m^3; mechanical bending strength must comply with class C20/25, and its thermal conductivity coefficient λ = 0.59 W/m°C (Kumar Mehta, 2014).

During the last decades more attention was payed to choose the new test methods in compliance with European construction standards (Klimiashvili, 2017).

The purpose of the article is to determine the possibility to use the local materials to improve the characteristics of concrete.

The tasks of the article:
- to study the concrete components and its physical and mechanical characteristics;
- to establish the possibility of using the local materials based on zeolite and expanded clay sand;
- to study the effects of using different typical methods to investigate optimal results such as pre-saturation, mixing, drying, and chemical admixtures.

1. Study of the cement structure

When calculating the composition of concrete, an analysis of the materials was carried out and their following characteristics were determined: Cement, which is one of the main components of concrete, the physical and mechanical characteristics of concrete depend on the activity of cement. In the experimental study, Rustavi plant cement CEM II B-P32.5 N/R was used, which is made on the basis of an active pozzolanic additive and has stable strength, this cement has passed laboratory tests in accordance with EN 196-1 and EN 197-1. The activity of cement on quartz sand mined in Georgia was also determined (Ghvinepadze et al., 2011), the test results were processed and compared with each other, and their final results are shown in Table 1.

Table 1. Test results of Rustavi cement (*own research*)

Party N	Normal thickness of cement paste %	The % of cement grinding purity (passed through 008 sieves)	Cement activity on standard sand kgf/cm^2	Cement activity on the locally sand kgf/cm^2
1	27	89.7	377	369
2	27	92.1	383	378
3	27	90.9	379	370

All the tests had been done in the Georgian Technical University's science laboratory. For testing we used: hydrostatic scale "STSJ-2"; laser rangefinder "Leica"; electronic test hammer "SILVER SCHMIDT"; Ultrasonic device "Pundit"; vibrating sieve "STSJ-3"; cement consistency meter "STSC-1"; sand equivalence testing device "STSD-2"; "STYE-2000C" concrete bending test pressure; laboratory oven (drying cabinet) "STHX-2A"; "KZJ-5000n" cement bending testing machine; concrete mixer "STWJ-60"; concrete molds; Kern removal device; Vika device "STWKY-1".

Test results of Rustavi cement were obtained from the quarries of Itavazi village, Sachkhere region. Studies have shown that cement samples made in both areas of the sand gave almost the same results. Samples prepared on sand of local origin showed a lower activity of only 3%. Expanded clay gravel and sand are used as artificial fillers, which are obtained by swelling and firing of easily soluble clays at 100-1250°C.

In accordance with the requirements of standard 8735-75, zeolite and expanded clay grains with a size of less than 5 mm were studied together with the sand of the Itavazi quarry in the local Sachkhere region, which we used as a concrete aggregate. The granulomeres composition of zeolite and expanded clay sands, their bulk density and sand modulus have been calculated. The results of the sand test are shown in Tables 2 and 3.

Table 2. Results of investigation of zeolite sand (*own research*)

Residual %	Sieve size, mm					> 0.14	M	General density g/cm^3
	2.5	1.25	0.63	0.315	0.14			
Private complete	23 23	11 34	19 53	20 73	22 95	5 100	2.78	0.84

Table 3. Results of examination of ceramsite sand (*own research*)

Residual %	Sieve size, mm					> 0.14	M	General density g/cm^3
	2.5	1.25	0.63	0.315	0.14			
Private complete	30 30	16 46	22 68	17 85	12 97	3 100	3.26	1.16

Fractional grains of zeolite and expanded clay 5-10 and 10-20 fractions were also tested.

Georgia is rich in natural zeolite rocks, which are mainly found in six regions of Georgia: Kutaisi, Sachkhere-Chiatura, Dzegvi-Tedzami, Akhaltsikhe-Aspindza, Tetri Sarko-Bolnis, Guria (Razmade, 2001). We have studied zeolite rocks in the Sachkhere-Chiaturi region. Natural zeolite belongs to nonporous framework alum inosilicates, which have a microporous structure and are characterized by a high penetrating ability of large organic molecules without changing their crystal structure.

In our case, for the experiment, the true and total densities were determined on the material dried to constant weight (Fig. 1 – the process of drying materials to constant weight) dried materials: perlite and zeolite (Fig. 2).

Fig. 1. Process of drying materials to constant weight (*own research*)

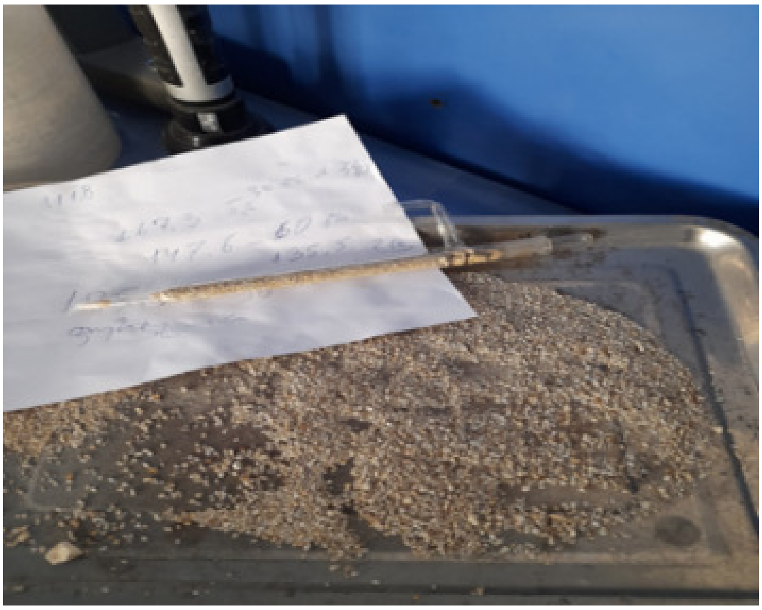

Fig. 2. Dried materials: perlite and zeolite (*own research*)

To determine the porosity of the zeolite, 3 scans were performed and the arithmetic mean was determined. The results are shown in Table 4.

Table 4. The porosity of zolite (*own research*)

Trial number	True density g/cm^3	General density g/cm^3	Porosity %
1	2.05	0.73	
2	2. 07	0.81	
3	2.0	0.68	
Arithmetic average	2.04	0.74	64

2. Study of the perlite chemical composition

We also used perlite from the quarries near Lake Paravani. This is a natural rock of volcanic origin, which acquires special properties as a result of crushing and subsequent high-temperature heat treatment. Perlite is a natural, environmentally friendly, sterile material that does not decompose, does not burn, does not rot and is not toxic. It is a non-fibrous material, harmless to humans, does not cause allergic reactions or skin irritation, and does not harm the climate of the building. Bio-stable and chemically inert (pH = 6.5±7). Such unique properties of perlite led to its widespread use in the construction industry.

Perlite has a fine concentric-round structure (pearlite structure), according to which it breaks up into rounded nuclei (pearls), resembling pearls with their characteristic luster. Perlite differs from other volcanic rocks in the content of bound water (more than 1%). Porosity can be 8-40%. Perlite can be black, green, red, brown and white in various shades.

Perlite chemical composition: silicon oxide SiO_2 70-75%; aluminum oxide Al_2O_3 12-15%; sodium oxide Na_2O 3-4%; potassium oxide K_2O 3-5%; iron oxide Fe_2O_3 0.5-2%; magnesium oxide MgO 0.2-0.7%; calcium oxide CaO 0.5-1.5%. Perlite is an extremely versatile material. It is distinguished by the unique property that it swells as a result of heating in a special oven at 1200°C and increases by 4-20 times its original volume. This swelling is caused by the presence of 2 to 6% bound water in the perlite rock. When fired at high temperatures (871-1200°C), the evaporation of water molecules in perlite causes it to expand.

The fermentation process also results in a special characteristic of perlite: its white color. Before firing, raw perlite is gray in color, but can also be green, brown, blue, or red. After drying, it usually takes on a white color. It prevents the spread of fire and begins to melt only at 1000°C. Perlite is a refractory product. Perlite is chemically inert, it is natural glass (aluminum, potassium, sodium silicate). It stabilizes over time. Expanded perlite is low-density, from 50 to 125 kg. per cubic meter. This is an excellent material for heat and sound insulation. Thanks to the closed empty micro-cells, perlite prevents heat conduction and radiation.

In lightweight concrete in the form of granules, a thermoplastic polymer-polystyrene with a size of 1.5-3 mm is used. The volumetric weight is 1.05 g/cm^3, which provides water resistance, heat and sound insulation.

3. Empirical testing process

The experiments were carried out with absolute safety. Hazards were identified in advance, safety data sheets were requested for all materials, risks were properly assessed and hazards were minimized.

This specific report is made using tables and formulas derived from empirical tests. Based on the high water demand of putty, to reduce water consumption, a penetrating waterproofing additive of 1.5% by weight of cement was used, which was mixed with a dry mix, and a superplasticizer 2% of water consumption, which we dissolved in water and mixed with the dry mix. Lightweight concrete mixes are made from pressure-type concrete mixes. First, coarse aggregates are added to concrete mixtures, then fine aggregates and binders. Water is supplied continuously. Mixing requires relatively more time than solid concrete, so micro-silicate was used as a plasticizing additive (Fig. 3).

Fig. 3. Lightweight concrete mix obtained in forced mix concrete (*own research*)

The light concrete experimental case is shown in Table 5 and the resulting concrete samples were molded in 10x10x10 molds and tested at 28 days/nights in Table 6.

Table 5. The light concrete experimental case (*own research*)

N of the concrete sample	Cement kg	Water L	Sand kg	Kermit kg	Zeolite kg	Perlite kg	Polystyrene kg
1	250	200	407	798	30	35	30
2	290	220	570	658	35	40	30
3	350	240	468	643	50	45	35
4	360	250	510	570	50	45	40

Table 6. The resulting concrete samples were molded in 10x10x10 molds and tested at 28 days/nights (*own research*)

N of the concrete sample	Concrete class	Cylindrical bending strength, N/mm^2	Cubic flexural strength N/mm^2	Mixture cone fit class
1	C20/25	20	27	S2
2	C20/25	23	28	S2
3	C20/25	22	27	S2

According to the results of the experiment, it was found that expanded clay and zeolite grains provide the strength of concrete, and during the tests, the damping ability of polystyrene was revealed, which was manifested by their significant deformation of the seam under the action of a breaking load of 0.5 R and restoration of this deformation to the end when the load was removed. The specified property of polystyrene concrete will probably give us the opportunity to use it in structures that work on dynamic and seismic loads in the foundations of low-rise buildings.

Conclusions

The conducted research develops the compositions of engobe mixtures in interaction with a ceramic base. The proposed coatings are designed for a single annealing of building products, which allows them to be produced using energy-saving technology. When using the compositions of the developed engobe coatings and observing the established conditions of the technological process, it is possible to obtain high-quality products that meet the requirements of the standards.

The lightweight aggregates improved the energy efficiency and sound insulation of the concrete, and on our recommendation, one of the buildings was covered with lightweight concrete. Work is underway to determine its thermophysical characteristics when exposed to negative temperatures.

In addition to the above, the composition of the local material makes it possible to improve the quality of concrete used in construction and improve the quality of facility operation.

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