საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 19(193), №1, 2025
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 19(193), no. 1, 2025

Materials Science

Complex Mineral Additive for Producing High-Quality Concrete

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(Presented by Academy Member Tamaz Shilakadze)

The influence of concrete additive obtained by dewatering and grinding the mass of crushed rocks brought by mud flows from the mountain massifs of Georgia on its strength has been studied. It is estimated that the additive replaces an average of 20% of cement in concrete, without reducing strength, thereby reducing CO_2 emissions and footprint ("carbon footprint") and concrete costs. It reduces the size and number of voids and pores in concrete; does not increase the water/cement ratio; prevents negative events caused by free lime (CaO_{free}) brought by cement added to concrete. *© 2025 Bull. Georg. Natl. Acad. Sci.*

dehydration, argillites, portlandite, pozzolanization, rehydroliming, pores and voids, bending, water impermeability, frost resistance

Cement and concrete made from cement are highly demanded products for people even in the 21st century. By 2023, global production of cement will reach 4.0 billion tons, and concrete will reach 10.0 billion m^3. According to the calculation ((4.0/8.0) billion), 0.5 t of cement and (10.0/8.0 billion) 1.2 m^3 of concrete are produced for 1 person living on earth.

The "carbonate footprint" released during the production of 1 ton of cement clinker is equal to 0.8 t of CO_2 on average when it is burnt at 1500°C [1]. In its turn, if the consumption of cement in traditional concrete is equal to 300-400 kg/m^3, then "carbon footprint" = 240-320 kg/m^3, i.e. per person (240-320) x 1.2= 288-384 kg/m^3, which is a global problem, it is too high and should be reduced.

According to EN 206-1:2013 [2], concrete is made of cement containing grains of 0-90 µm, fine filler with grains of 0-5000 µm – sand, coarse aggregate containing grains of 6(6000)-40(70) mm (gravel), by mixing with water.

According to BS EN 197-1:2011 [3], cement is mainly produced by ultrafine grinding in separator mills, and also – mainly on the basis of clinkers burnt by the "dry method". In the clinker burnt by the "dry method" the amount of CaO_{free} is equal to 2-3 weight % – which then goes into the concrete and causes negative results: unstable mineral portlandite $Ca(OH)_2$ is formed in the hardened concrete mass, which reduces the stability of the concrete. This is also a global problem and requires prevention.

When assessing the quality of concrete, only defects caused by mistakes made in the process of manufacturing concrete products are considered [4]. Technological deviations in the production of cement and concrete are not considered. In particular, the maximum sizes of ultra-finely ground cement grains in separator mills do not exceed 40-50 μm, and the minimum sizes of fine aggregate sand grains used in concrete are slightly less than 140 μm. Therefore, in modern concrete there is a shortage of 50-140 μm cement-sand grains (Fig. 1) and the so-called "filling defect in concrete", which is finally reflected in the mass of concrete and the formation of macro-sized voids on the surface (Fig. 2), which is also a global problem.

The mountain rivers of Georgia are characterized by a periodic flood regime. These floods create typical structural mud flow [5], which brings clayey mass containing silica (SiO_2) and alumina (Al_2O_3) turned into mud from the mountains to the place of accumulation with a capacity of not less than 200 m^3/s. In particular, every year the river Duruji from the Caucasus mountains brings and "collects" a mass containing no less than 0.5 ml/m^3 of stone-gravel-silty clay slate in the valley above Kvareli. This fact is a local problem, it is necessary to remove and utilize the mass of crushed mountain rocks brought down by mud flows from the mountains and utilized from the river bed, because otherwise devastating negative events and consequences for the city of Kvareli are expected.

A global-local construction problem is that during the construction of foundations, tunnels and other facilities, an excess amount of clay soil

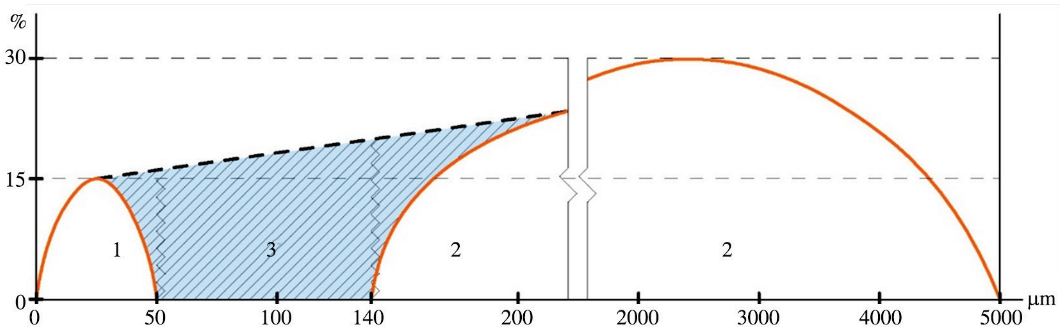

Fig. 1. Granulometry of cement and sand grains in concrete mix: 1 – cement; 2 – sand; 3 – lack of 50-140 μm grains of cement and sand in the concrete mixture.

Fig. 2. Macro-sized voids on the concrete surface.

containing silica (SiO_2) and alumina (Al_2O_3) is inevitably generated, which must be removed from the construction site and utilized [6].

The idea of the research is to create complex mineral additive ("CMA") for filling voids caused by the lack of 50-140 μm grains in concrete and pozzolanic property [capable of hydraulic reaction with $Ca(OH)_2$, or containing SiO_2 or n Al_2O_3*m SiO_2], which, with the "presence" of 50-140 μm grains, ensures the elimination of structural voids in the mass and surface of the concrete, minimizing unstable $Ca(OH)_2$ due to its modification into water-stable compounds by the pozzolanic reaction [7].

Materials and Methods

The filling additive is produced by utilization and grinding the mass of crushed mountain rocks brought down by mud flows or the surplus soil generated at construction sites; it is ground so that the average size of the filler grains is greater than the maximum size of the cement grains used in concrete and less than the minimum of sand grain (know-how); – During hardening, concrete undergoes re-hydroliming by forming structural crystal hydrates.

Without reducing its strength the filling additive replaces ≤ 20% of cement in concrete. Thus, it reduces CO_2 emissions and footprint ("carbon footprint"), and the cost of concrete; improves flowability of concrete mixture; reduces the size and number of voids and pores in concrete; prevents negative events caused by free lime (CaO) added to concrete with cement; compared to ordinary cements, the cost is 3-4 times lower.

We conducted experiments and compared the physical and mechanical characteristics of concrete samples made without addition (base), and concrete samples made with addition of limestone "filler" and "CMA":

1. Concrete samples (base) without additives (cubes and bars) with a cement consumption of 350 kg/m^3;
2. Concrete samples (cubes and bars) made with the addition of limestone filler at a cement consumption of 320 kg/m^3, limestone filler consumption at 40 kg/m^3;
3. Concrete samples (cubes and bars) made by "CMA" with cement consumption at 320 kg/m^3, "CMA" consumption at 40 kg/m^3. Before the test, the samples were stored in the climatic chamber of the laboratory, where the temperature was 20^{0}C±2, and the humidity: 95%±4%.

Samples were tested for compression and bending strength, waterproofing and frost resistance.

The specimens were tested on compression at 28 days of age. The compression test of the samples was carried out in accordance with the normative document EN 12390-3-2009 ("Hardened concrete test – Part 3: Flexural strength of the test samples") on the compression test machine CONTROLS ADVANTES T9 C5600/FR.

As a result of the research, the following was established:

- The average value of the compressive strength of the base samples of the age of 28 days is 36.06 MPa (360.6 kgf/cm^2, brand 350), which corresponds to the B27.5 class of concrete.
- The average value of the compressive strength of samples with limestone filler of the age of 28 days is 41.85 MPa (418.5 kgf/cm^2, brand 400), which corresponds to the B30 class of concrete.
- The average value of the compressive strength of the "CMA" samples of the age of 28 days is – 47.93 MPa (479.3 kgf/cm^2, brand 500), which corresponds to the B35 class of concrete.

The specimens were tested in bending at the age of 28 days. Testing of the specimens was carried out in accordance with the European standard EN 12390-5-2009 ("Testing of hardened concrete – Part 5: Flexural strength of the test specimens") using a press of CONTROLS company and flexural testing frame 50-C1601/FR. The bending strength of the sample was calculated based on the following formula:

$$f_{cf} = 3 \times F \times \frac{I}{2} \times d_1 \times d_2^2,$$

where: f_{cf} is the bending strength in MPa (N/mm^2); F is the maximum load, defined in Newtons; I is the distance between the clamping rollers, defined in mm; d_1 and d_2 are the dimensions of the sides of the section, determined in mm.

The bending strength is calculated to the nearest 0.1 MPa (N/mm^2).

As a result of the research, the following was established:

- The average value of the bending strength of the concrete samples (base) without additive was – R=5.11 MPa.
- The average value of the bending strength of the samples of concrete with limestone filler under the concentrated force is R=5.62 Mpa.
- The average value of the bending strength of concrete samples with “CMA” under the concentrated force is R=6.36 MPa.

Samples of 15*15*15 cm size (3-3 pieces) were tested for water permeability. The test of the samples for water permeability was carried out on the 55-C0244/BV device of the company CONTROLS in accordance with the requirements of the European standard EN 12390-8.

The depth of water penetration after 72 hours was found:

- Without addition (base) samples – No. 1 sample – 40 mm, No. 2 sample – 27 mm, No. 3 sample – 38 mm.
- Samples with limestone filler – sample No. 1 – 20 mm, sample No. 2 – 30 mm, sample No. 3 – 20 mm.
- Samples with “CMA” – Sample No. 1 – 15 mm, Sample No. 2 – 17 mm, Sample No. 3 – 15 mm

The depth of water penetration is not limited by the European standard, it is determined by the designer depending on the working conditions of the concrete and the protective layer of the reinforcement. By the German Committee for Reinforced Concrete (“Deutsher Ausschup fur Stahlbeton” 2003), a certain limitation on the depth of water penetration (not more than 50 mm) has been adopted. Of the samples we tested, all samples meet this condition, but the best results were shown by samples with “CMA”.

Samples of all three series were tested for frost resistance according to GOST 10060-2012 (EN 123990-9:2006). The samples withstood 200 freeze-thaw cycles without a significant decrease in strength, namely:

- The average compressive strength of the base control samples was 36.06 MPa, and the average strength after 200 freeze-thaw cycles was 35.53 MPa. The decrease in hardness amounted to – 1.47%, which is less than the 5% required by the standard;
- The average compressive strength of control samples made with limestone filler was 41.85 MPa; And after 200 freeze-thaw cycles, the average strength was 41.38 MPa. The decrease in hardness amounted to – 1.12%, which is less than the 5% required by the standard;
- The average compressive strength of the control samples made by “CMA” was 47.93 MPa; And after 200 freeze-thaw cycles, the average strength was 47.82 MPa. The decrease in strength amounted to – 0.23%, which is less than the 5% required by the standard.

Although after 200 freeze-thaw cycles, the samples of all three series met the requirements of the standard, but the “CMA” samples showed the lowest percentage of decrease in hardness.

Conclusion

Concrete samples made with complex mineral additive showed the best results in terms of bending strength, water permeability and frost resistance (47.93 MPa, 6.36 MPa, 15.7 mm and 0.23%), next were the concrete samples made with limestone filler (41.85 MPa, 5.62 MPa 23.3 mm and 1.12%) and finally the samples without addition (base) concrete (36.06 MPa, 5.11 MPa, 35 mm and 1.47%).

The work is supported by Shota Rustaveli National Science Foundation of Georgia (grant number AR-22-2064).

მასალათმცოდნეობა

კომპლექსური მინერალური დანამატი მაღალი ხარისხის ბეტონის დასამზადებლად

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შესწავლილია საქართველოს მთების მასივებიდან ღვარცოფებით მოტანილი დამსხვრეული ქანების მასის გაუწყლოება-დაფქვით მიღებული ბეტონის დანამატის გავლენა მის სიმტკიცეზე. დადგენილია, რომ სიმტკიცის შემცირების გარეშე დანამატი ცვლის ბეტონში ცემენტის საშუალოდ 20%-ს, რითაც: ამცირებს CO2-ის გამოყოფას და კვალს („Carbon footprint") და ბეტონის თვითღირებულებას; ამცირებს ბეტონში სიცარიელისა და ფორების ზომას და რაოდენობას; არ ზრდის წყალ/ცემენტის თანაფარდობას; ხელს უშლის ბეტონში ცემენტით შეტანილი თავისუფალი კირით (CaOთავ.) გამოწვეულ ნეგატიურ მოვლენებს.

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Received October, 2024