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Properties of concrete modified with mineral additives

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HIGHLIGHTS

- Mineral additives are among the most promising of concrete components in the development of new building materials.
- Replacement of cement with mineral additives can be increased concrete density, compressive strength, freeze-thaw resistance.
- Mineral additives can be used for modification of cementations systems.

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ABSTRACT

Concrete is the most widely used building material that is obtained by curing the mixture prepared from coarse and fine aggregates, cement and water. The properties of concrete depend on the quality and properties of the aggregates, w/c ratio, the uniformity of compression of the mix. Compressive strength of concrete is one of the most important properties. The present paper analyses the effect of mineral additive content on the properties of concrete. Materials used for the test: Portland cement CEM I 42.5 R, 0/4 fraction sand, 4/16 fraction gravel, mineral additive, polycarboxylatether based superplasticizer and tap water. Concrete mixes of 9 compositions were made by adding 0%, 2.5%, 5%, 7.5% and 10% of mineral additives by weight of cement. The tests revealed that the addition of mineral additives up to 10% increases the compressive strength of concrete. According to the test findings the compressive strength of hardened cement paste containing 10% of mineral additives increased 0.99% compared to the control mix. After 7 and 28 days of curing the ultrasonic pulse velocity in specimens with mineral additives increased 2.6% and 4.1% respectively. With the increase of mineral additives content up to 10%, water absorption of concrete reduces and the predicted freeze-thaw resistance increases.

1. Introduction

Different additives are used to control technological properties of concrete mixes as well as physical and mechanical properties of hardened concrete. It is important to investigate the effect of these additives on the physical and mechanical properties of concrete in order to achieve the effective performance of concrete and the required properties and durability of hardened concrete.

Mineral additives of concrete are dispersive natural and technical materials (mainly inorganic and non-water-soluble as opposed to chemical additives) described by the particle size less than 0.16 mm (as opposed to aggregates). With mineral additives added to the concrete mix the strength of concrete with the same or higher w/c ratio increases [1].

Mineral additives (zeolites, SiO_2 micro dust etc.) are some of the most prospective components of concrete in the development of new building materials such as high performance concretes, special concretes absorbing heavy metals or suppressing radioactive radiation. These additives modify and accelerate Portland cement hydration process, change its physical characteristics and mechanical behaviour. There a number of studies investigating the use of silica fume, coal, zeolites and ash as concrete supplements (pozzolanic additives) [2,3]. Zeolites contain a high content of SiO_2 and Al_2O_3. Silica dioxide and ash, like other pozzolanic materials, can increase concrete strength through the reaction of $Ca(OH)_2$ with pozzolans. Zeolites, like other pozzolanic materials, give higher strength to concrete compared to cement. Zeolites, however, also induce the occurrence of undesirable products such as alkalis and other complex compounds [4–6].

Researchers have found that zeolites of different modifications act as pozzolanic additives in concretes, during cement hydration increase CSH and CAH gel phases, which increase the resistance of Portland cement compositions to acids and sulphate corrosion and increase its durability [7].

Both natural zeolites of almost 50 types (clinoptilolite, mordenite, philipsite, ernonite, chabazite, vermiculite etc.) and artificial

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zeolites synthesized for special purposes (A, X, Y, L, ZSM-5 etc.) are widely used [8].

The use of natural zeolites as pozzolanic materials in construction dates back 3000 years, to the Greek and Roman periods when zeolites occurred as altered volcanic ash, tuff, and trass were used with lime in mortars and concretes for construction. The Romans used Neapolitan Yellow Tuff near Pozzuoli, Italy in construction of aqueducts, public buildings, and highways. The lime zeolite combination showed excellent cementitious property. Natural zeolite tuffs have been used for many years for cement pozzolans in Serbia, Germany, Italy, Bulgaria, China, and Russia [9,10].

The main building materials with zeolite production takes place in the following directions: binders, concrete, autoclaved lime products [11]. Synthetic zeolites can be used as adsorbents or conventional water softening agents, detergents [12,13].

The use of zeolite additives in cement structures is broadly described in scientific literature. According to Yun-Sheng, Chen-Lin, zeolite added at 15% to the cement mix increases the early-age strength of concrete. Hydration time is reduced with the use of zeolites [14].

Turkish researchers made tests with 5, 10, 20 and 40% of zeolite added to concrete mixes. The compressive strength was measured after 1, 2, 7 and 28 days of curing. The results showed that after 24 h of curing the compressive strength of concrete with zeolite additive was higher compared to control specimens. The same trend was observed after 2 and 7 days of curing [15].

Researchers Ahmadi and Shekarchi studied the effect of zeolite on mechanical characteristics and durability of concrete, compared to other cement additives. The tests showed that although the reaction of zeolite with portlandite was different than that of SiO_2 micro dust, zeolite had good pozzolanic activity. Besides, the researchers found that compressive strength, water absorption, oxygen permeability, chloride penetration and electric resistance characteristics of concrete with different content of zeolite were similar or even better than the same characteristics of the mix prepared with silica fume [16].

Canpolat and co-authors studied the characteristics of concrete where zeolite was used as an active mineral additives. 5–35% of cement was replaced by zeolite. The test results revealed that the highest compressive strength after 28 days of curing was achieved when 20% of zeolite was added. According to the tests, the optimal limit of fly ash used together with zeolite was 10–25% of zeolite and 5% of fly ash [17].

Latvian researchers have tested the compressive strength of regular concrete modified with aluminosilicate additives. The compressive strength of concrete was tested after 7, 28 and 155 days of curing. After 7 days concrete specimens with pozzolanic admixture had 15.2% higher compressive strength compared to the control specimen, after 28 days of curing in water the compressive strength increased more than fourfold, namely 26.38%. Later, the specimens were cured for 127 days in air at 20 °C. After 155 days of curing the compressive strength of specimens without the additive was 61.1 MPa, whereas the compressive strength of specimens with the additive was 67.4 MPa [18].

Researchers have also studied the properties of concrete modified with catalysts used in the oil industry. Stonys with co-authors have found that the compressive strength of concrete modified with 5% of catalyst increases 25%. Paya with co-authors also used the catalyst waste added at 20% to concrete mixes; the compressive strength of concrete was higher compared to control specimens [19,20]. Aleknavičius and Antanovič according that catalysts waste (zeolite) can be used for fire-resistant cement materials [4].

According to Yun-Sheng and co-authors, the compressive strength of concrete with 10% catalyst admixture increases 7–11% after 3–28 days of curing. The compressive strength of mortars containing 10% of catalyst additive increases 8–18% [14].

Chinese researchers Gai-Fei, Qiang and co-authors investigated the effect of silica fume and fly ash on the freeze-thaw resistance (durability) and porosity of concrete. The test results showed that the addition of pozzolanic additives to the concrete mix resulted in increased pore volume and the average pore size, thus better freeze-thaw resistance of concrete [21].

The aim of the study presented in this article was to determine the effect of mineral on the alumosilicate bares additives on the properties of hardened concrete and its durability.

2. Materials and research methods

Portland cement of type CEM I 42.5 R complying with EN 197-1:2001 requirements. Portland cement characteristics are presented in Table 1. Chemical composition of the cement, natural zeolite is presented in Table 2.

0/4 fraction sand complying with EN 12620:2003 requirements was used as the fine aggregate. 4/16 fraction gravel complying with EN 12620:2003 requirements was used as the coarse aggregate. Physical characteristics of the sand and gravel are presented in Table 3.

High quality polycarboxylatether based superplasticizer was used to improve the properties of concrete. This superplasticizer accelerates the initial setting and provides the early-age strength to concrete. It is used in the manufacturing of high-performance concretes. Clean water without harmful impurities that have a negative effect on the setting of concrete, namely potable water complying with EN 1008:2003, was used to prepare the concrete mix. Natural zeolite clinoptilolite $(Na,K,Ca)_{2\text{-}3}\,Al_3(Al,Si)_2Si_{13}O_{36}12H_2O$ is a microporous aluminosilicate hydrate of alkali metals or alkaline-earth metals. Clinoptilolite is used to absorb different materials from gas and solutions due to its unique properties: resistance to high temperatures, aggressive media, ionizing radiation, alkaline-earth metals and some heavy metals. It is also successfully used in the production of molecular sieves dues to its unique crystalline structure.

Additive of concrete (aluminosilicate) is a pozzolanic concrete additive based on amorphous alumo-silicate. It concerns a synthetically manufactured material, not an industrial by-product. Apart from a high uniformity long term availability is also ensured. New generation materials like this aluminosilicate based on special nanocrystallizers have been recently developed. These new materials improve the properties that are crucial for the durability of high-performance concrete. In addition to reducing chloride migration, an exceptional chemical and acid resistance of the high-performance concrete can be achieved with this aluminosilicate. The concrete structure is simultaneously reinforced right down to nano scale, density is improved and compressive and flexural strength as well as abrasion resistance of the high-performance concrete is increased.

Table 1
Portland cement characteristics.

Properties	Portland cement CEM I 42.5 R
Specific surface, cm^2/g	3700
Particle density, kg/m^3	3200
Bulk density, kg/m^3	1200
Standard consistency paste, %	25.4
Initial setting time, min	140
Final setting time, min	190
Compressive strength after 7 days, MPa	28.9
Compressive strength after 28 days, MPa	54.6