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The development of alkali-activated cement mixtures for fast rehabilitation and strengthening of concrete structures

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Abstract

This study was dedicated at design of alkali-activated (slag) cements with high-modulus soluble silicates and concretes based on them which would possess workability retention, quick and steady strength gain, high strength characteristics, etc. Specific features of mode of deformation (in tension under bending stresses) of fine aggregate alkali-activated cement concretes were studied. The results of this study showed that the modified alkali-activated cements and concretes exhibited high tensile strength in bending and high ratios of this strength to compressive strength. The results of analysis of deformation of the alkali-activated cement concretes under action of bending stresses showed that high values of crack resistance, impact resistance and increased deformability could be expected. Basic strength and deformation characteristics of the developed repair mortars and concretes after additional optimization of their constituent composition are provided and discussed.

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Keywords: alkali-activated cement; compressive strength; deformation properties; fracture; fragmentation; repair mortar and concrete; setting times; strength; tensile strength in bending.

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1. Introduction

Microstructure of concrete plays a key role on physico-mechanical, deformation characteristics and durability and it should be taken into account in design of artificial stone and in choice of their intended use.

Alkali-activated slag cements (further, AAC), and concretes, on the contrary to portland cement ones, have a complicated and unique microstructure it does not contain any high-basic hydrate phases, does not have a rigid framework from portlandite and calcium aluminates, is highly dispersed one with well developed specific surface, contains predominantly low-basic calcium hydrosilicates, alkaline and alkaline-alkaline earth aluminosilicate hydrates[1]. These specific features explain high strength characteristics of these materials, high ratios of tensile strength in bending to compressive strength, good elastic-plastic deformation behavior]. For repair application the preferred alkaline activators were sodium silicates with (silicate) modulus of 1…2, allowing to obtain AACs and concretes with compressive strength in excess of 60 MPa. However, as was established, the most preferred alkaline activators are soluble silicates with (silicate) modulus (Ms) higher than 2, which allow for easy workable mixtures with compressive strength of 10…20 MPa at an age of 2…3 h and 80…120 MPa at an age of 28 days [2-3].

One of negative features of high strength AACs and concretes, similar to portland cement clinker-based materials, is that with higher compressive strength their crack resistance tends to decline [4-5].

A target of the study was to design super quick hardening and high strength AACs and concretes with high ratios of tensile strength in bending to compressive strength, and good elastic-plastic deformation behavior.

2. Raw materials and testing techniques

Ground granulated basic blast-furnace slag of chemical composition and fineness of 4420 cm^2/g (by Blaine) was used in the study: SiO_2 – 35.80; Al_2O_3 – 10.61; CaO_4 – 2.58; MgO – 6.81; modulus of basicity (according to Ukrainian standard definition) ($CaO+ MgO/ SiO_2+Al_2O_3$) – 1.06; glass phase – 56.0% by mass.

Soluble sodium silicates (modulus = 2.9 and density = 1400 kg/m^3) were used as alkaline components.

Salt $Na_3PO_4 \cdot 12H_2O$ (further, TNP) was chosen as setting time retarder of the AACs under study. Contents of TNP were chosen experimentally to provide the initial setting not earlier than 15 min, as required for super quick hardening portland cement-based systems. The TNP was preliminarily dissolved in sodium silicate solution with following bringing of the resulted homogeneous solution to required densities of 1380…1400 kg/m^3.

In order to improve elastic behavior of the AAC pastes, mortars and concretes, additives selected from the group of cross-linking additives were used [6]. These additives are polyfunctional organic compounds that are capable to bind surface groups of silicooxygen oligomers with the help of hydrogen bonds by cross-linking molecules of silicic acid. The most known among these compounds are spirits, ethers, ketones, amines and amides [7-8].

According to the results of preliminary study, two additives have been chosen as modifying agents: glycerol and polyacrylamide (trade name- Agocel S 2000). The latter, being added to soluble silicate, adds to it an ability to be deformed at free outflow with the formation of elastic needle-like form.

Influence of the above listed additives, taken separately and in combination, on such properties as setting times, workability retention, viscosity, etc and physico-mechanical properties was studied on cement pastes and fine aggregate and coarse aggregate concretes.

Preparation of the AAC pastes and cement- sand mortars was carried out in a standard mixer of the Hobart type, coarse aggregate concretes – in a 30 l-concrete mixer of forced action. Mono-fractional sand was used as fine aggregate in cement- sand mortars and local river sand (coarseness factor = 1.2) was used as fine aggregate in concretes.

A ratio of volume of soluble silicate to mass of slag (silicate solution to slag, further, SS/S), in preparation of the cement-sand mortars was chosen experimentally until a flow value measured on a standard jolting table ≥115 mm would be obtained. In preparation of the concretes a ratio SS/S was chosen in such a way that a slump of 5…8 cm measured using a standard cone would be obtained.

Curing conditions for all specimens prepared from cement pastes and cement- sand mortars were: after preparation and until 3 h – were kept in molds in normal conditions, after 3 h were demolded and placed for further storage under normal temperature-humidity conditions (RH = 95…100 %, t = 20±2 °C), for the coarse aggregate concretes after 3 h of hardening in molds in normal conditions the specimens were demolded and placed into water.