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Original Research Paper

Artificial aggregates based on granulated reactive silica powders

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ABSTRACT

This paper reports on the development of artificial aggregates based on granulated reactive silica (AAGS) powder materials activated by alkaline components. The alkali content was optimized depending on the properties of the reactive silica (RS) material. The best RS component for AAGS was determined to maximize the volume of synthesized soluble polysilicates. Additional research was conducted to evaluate the materials for the formation of a strong shell for AAGS. The effect of RS and AAGS composition on the structure of hardened cement composite was investigated.

1. Introduction

Lightweight construction materials such as lightweight aggregate (LWA) concrete are in high demand because of their attractive mechanical performance and thermal insulating properties [1–4]. One of the most considerable disadvantages of LWAs that limits their application in concrete is related to a large volume of open pores and, therefore, high water absorption. Traditional LWAs are manufactured by firing at relatively high temperatures; therefore, conventional technology is characterized by a considerable energy consumption and dust emissions.

It is attractive to design a new type of aggregates which can provide the capability of improving the interface with cementitious matrix and reducing the water absorption while maintaining a low average density and thermal conductivity. Lightweight aggregates based on granulated powders (i.e. fly ash, alumosilicates, reactive silica) which do not require firing in a kiln are the most promising materials for LWAs. Suitable diatomites, which occur as large fossil deposits in terrestrial environments can be used as a reactive silica (RS) material. This group of minerals, depending on the genesis, includes tripoli, opoka and others. These sedimentary rocks consist of the residue shells of diatoms, radiolarians, sponge spicules or small globules of opal-crystobalite particles. The annual production of diatomite in Russia is at the level of 80 thousand tons. The United States and China are the major manufacturers of diatomite with an annual production of 677 and 350 thousand metric tons, respectively [5].

The content of RS in these rocks can vary from 50% to 90%. The phase composition of RS minerals is mainly represented by opal (56–98%), cristobalite (<20%) and quartz (5–35%) [6].

Aggregates based on amorphous silica rocks have been used in LWA concrete [1]. The RS-alkali based LWA interact within the range of concrete curing temperatures (including steam curing) and result in a strong product. Under the concrete steam curing the grains of LWA are reduced due to the formation of soluble alkali-rich phases and, at the same time, the aggregate-cement paste contact zone is densified by alkali solution, Fig. 1 [7–9]. The main challenge related to proposed approach is related to some sensitivity of early age hydrating cement structure to internal stresses and possible induction of alkali-silica reaction when excessive quantities of alkalis are used. However, RS is a promising raw material for LWA when designed for prolonged action (to reduce the internal stresses) and when amorphous silica is incorporated into water-insoluble phases. This research was focused on investigation of the effect of a steam treatment of LWA concretes with artificial aggregates based on granulated reactive silica powders (AAGS) of genetic formula "SiO_2–ROH", where R is an alkali metal ion. It was proposed that under thermal gradients the liquefied silica-alkali phase diffuses from the silica grains into cementitious matrix densifying the contact zone (Fig. 1).

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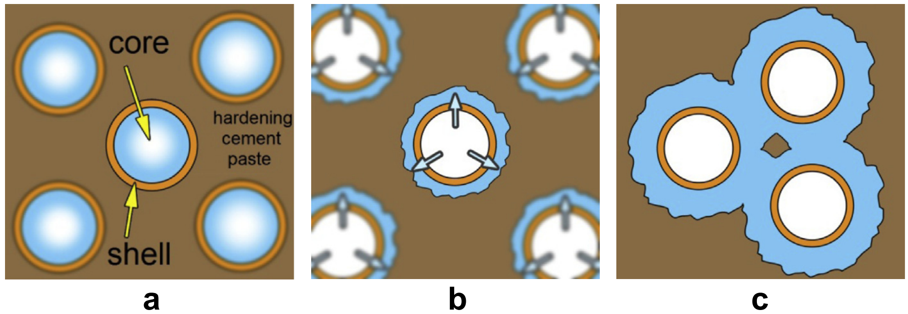

Fig. 1. The formation of AAGS based composite. (a) The initial structure. (b) Thermally induced diffusion. (c) The structure of hardened concrete with densified contact zone.

Table 1
Characteristics of lime.

Properties	Slaked lime	Unslaked lime
Content of active CaO + MgO (%)	>60	>80
Active MgO (%)	⩽5	⩽5
CO_2 (%)	–	⩽5
Unreacted grains (%)	⩽11	–
Content of hydration water (%)	⩽0.5	–
Slaking time (min)	–	⩽8

Table 2
Chemical composition of portland cement.

Type of cement	Chemical composition (%)						
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI
CEM II/A-S 32.5R	21.8	5.40	4.30	66.4	0.58	2.35	0.51
CEM I 42.5	21.52	5.83	4.50	66.03	0.57	2.42	0.30
CEM II/A 32.5	31.28	5.25	4.33	50.42	1.16	3.20	0.84

On the first stage of thermally induced curing (Fig. 1a) the hydration of portland cement results in formation of a strong frame work around non-activated AAGS. Along with the hydration process (the second stage, Fig. 1b), an activation of AAGS's core is realized at a steam curing. At this stage, the diffusion of amorphous silica and formation of polysilicate solutions takes place followed by the densification of AAGS shell and concrete matrix. Further densification of AAGS contact zone (Fig. 1c) is realized with polymerization and polycondensation of newly-formed polysilicates.

2. Experimental program

2.1. Materials

The raw materials for AAGS included the range of alkali products: NaOH, Na silicate, Na fluorsilicate, quicklime, hydrated (slaked) lime, chalk and three types of portland cement: CEM II/A 32.5R (supplied by "Belgorod cement"), CEM I 42.5 (supplied by "Oskolcement"), CEM II/A 32.5H (manufactured by "Mordovcement"). The silica components for AAGS core included opoka (Alekseevskoe deposit, Mordovia) and tripoli (Stal'noe deposit, Belarus). The silicic acid ($SiO_2{\cdot}nH_2O$) was used as a model system for investigation of a contact zone. The same types of portland cement were used to obtain the "model" cement paste and mortar for the study on contact zone. Fine sand (Ziborovskoe field, Belgorod region) with a fineness modulus of 1.4 was used as an aggregate for "model" mortars.

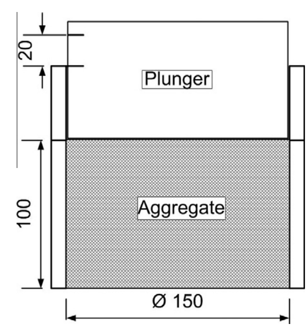

Fig. 3. The apparatus for testing of the crushing strength of aggregates.

The properties of slaked lime and chemical composition of portland cement are presented in Table 1 and 2 respectively.

2.2. Test methods

The investigation of the cementitious matrix was performed using the methods of Infra-Red Fourier Transform Spectroscopy, FTIR (using FTIR Spectrometer VERTEX 70) and electron microscopy (High-Resolution Scanning Electron Microscopes Supra 50 VP and Dual Beam Electron Microscope Quanta 3D FEG). The

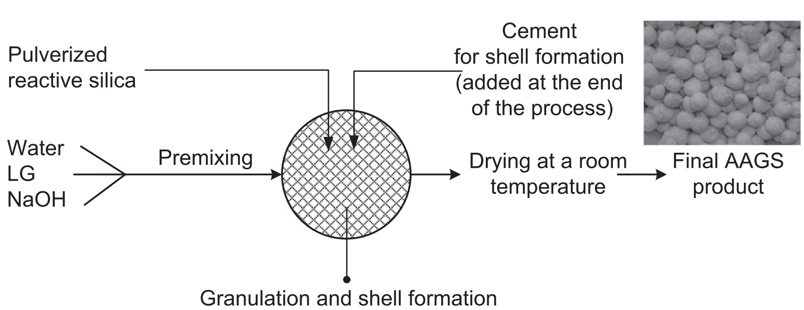

Fig. 2. The process of AAGS production.