Construction and Building Materials 115 (2016) 125–131

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Influence of paste thickness on coated aggregates on properties of high-density sulphoaluminate cement concrete

Sun Keke [a], Zhou Xiangming [b], Gong Chenchen [a,*], Ding Yanyu [a], Lu Lingchao [a]

[a] Shandong Provincial Key Laboratory of Preparation and Measurement of Building Materials, Jinan, Shandong 250022, China

[b] Department of Mechanical, Aerospace and Civil Engineering, Brunel University London, Uxbridge, Middlesex UB8 3PH, United Kingdom

HIGHLIGHTS

- High-density sulphoaluminate cement concrete is prepared with improved DMAD.
- The shape of aggregates is assumed square and spherical to calculate paste amount.
- Effect of paste thickness on the properties of HDSC was studied.

ARTICLE INFO

Article history:
Received 15 December 2015
Received in revised form 23 March 2016
Accepted 5 April 2016
Available online 13 April 2016

Keywords:
Sulphoaluminate cement concrete
Fuller curve
Densified mixture design algorithm
Coating thickness
Durability

ABSTRACT

An improved method for the densified mixture design algorithm and Fuller curve were used to design high-density sulphoaluminate cement concrete (HDSC). The performance of HDSC is significantly influenced by the paste thickness on the coated aggregates. Sulphoaluminate cement concrete mixtures containing aggregates coated with 3 different paste thickness of t = 10 μm, 20 μm, and 30 μm and water-binder ratios of 0.25, 0.30 and 0.35 were prepared. The results of experiments show that paste thickness on the coated aggregates significantly influences the mechanical properties and durability of HDSC. With the increase of paste thickness, the compressive strength is increased, but the electrical resistivity is decreased, particularly at the early ages of 1 and 3 days. The sulfate corrosion resistance coefficients of HDSC are larger than 1.0, the total porosity can be less than 7%, and the micropore (i.e. with pore size less than 20 nm) can be larger than 70%.

1. Introduction

Sulphoaluminate cement is a type of "low energy" cement compared to Portland cement [1], possessing advantageous properties such as high early-age compressive strength, short setting time and shrinkage compensation and it is typically used in the marine engineering field [2–4]. However, as a special type of cement, the mechanical properties and durability [5,6] of sulphoaluminate cement concrete (SACC) has not been well studied. Under harsh environments, the harmful external ions and water can easily permeate into the concrete interior, destroying its structure and shorten its service life. However, a compact concrete structure can lead to improved strength and durability. The importance of pore structure and its impact on durability has been highlighted in numerous studies [7]. Many researchers also found that the concrete pore structure improved the interfacial transition zone (ITZ) and dominated engineering properties, such as strength and durability [8,9]. For such reasons, high-density concrete has been widely used to achieve outstandingly durable concrete structures.

However, it must be noted that little work has been conducted on SACC mixture design as a high-density concrete. Therefore, the major work required is designing an appropriate mix proportion to produce the high-density sulphoaluminate cement concretes (HDSCs). The densified mixture design algorithm (DMDA) is derived from the maximum density theory and excess paste theory, proposed by Hwang et al. [10–12]. This method is based on the hypothesis that the physical properties can be optimized when the packing density is high. The major difference from the other mixture design algorithms is that instead of partial replacement of cement, DMDA incorporated the use of fly ash to fill the void between aggregates and hence increase the density of the aggregate system. In such a way, the cement paste content can be reduced without affecting the other properties such as workability, and strength [13]. Lots of research [13–16] shows that it is feasible to produce the eco-friendly construction bricks, lightweight

* Corresponding author.
E-mail address: gongccedu@163.com (C. Gong).

http://dx.doi.org/10.1016/j.conbuildmat.2016.04.018
0950-0618/

concrete, high-performance concrete and self-compacting concrete using the DMDA method with the incorporation of an admixture, such as fly ash or slag powder. However, to simplify the derivation, it is necessary to assume that the aggregate is spherical, which is physically very hard to achieve and thus gives rise to errors.

In additional, it is commonly thought that the cement paste volume is a key factor in achieving a desirable concrete workability and durability [17–19]. A work studied the effect of cement content on transport processes important to the durability of concrete structures, such as electrical conduction and chloride diffusion. It was found that the resistance to transport reduced as cement content was increased [20]. Hwang et al. proposed a particular DMDA, in which the concept and formula of the paste thickness on coated aggregates were introduced. A complete and precise formula to estimate the optimum coating thickness on the aggregates was derived to ensure the use of sufficient coating paste and a dense concrete structure is obtained [21]. Kolias and Georgiou studied the effect of paste volume and of water content on capillary absorption and strength on concrete mixes. It is found that strength increases and capillary absorption decreases when the volume of the water or the volume of the paste decreases [22]. Chen et al. demonstrated that the paste thickness on the coated aggregates has a positive effect on the slump flow, concluding that a thickness of 42 μm produced self-compacting concrete which flowed to a diameter of 680 mm [23]. Last but no least, using less cement reduces energy consumption and CO_2 emissions associated with its production process.

In this paper, an improved DMDA method is developed to simplify the calculation process. Introducing the assumption that the aggregates are square and spherical in shape allows a more accurate engineering design requirement to prepare HDSC. The Fuller curve was used to calculate the aggregate gradation, and the sieve analysis was used to calculate the specific surface area of aggregates. Sulphoaluminate cement, replaced by approximately 5% superfine slag powder, and 10% fly ash, both by weight, was used as the cementitious materials for preparing the HDSC and the improved DMDA calculated the dosage of cementitious material. Finally, the effects of paste thickness around the aggregates on mechanical and durability properties of HDSC were investigated.

2. Raw materials and methods

2.1. Sulphoaluminate cement and admixtures

Sulphoaluminate cement of strength class 42.5, fly ash and slag powder were imported from mainland China. The chemical compositions of the sulphoaluminate cement, fly ash and slag powder are shown in Table 1. The average particle size of fly ash and slag powder are 14.34 μm and 2.98 μm, respectively. The superplasticizer (SP) used was a polycarboxylate polymer, and its water-reducing capacity in SACC was over 20%.

2.2. Aggregates

River sand (0.075–2.36 mm in size) was used as fine aggregates with an apparent density of 2710 kg/m^3, and crushed natural stone (2.36–16 mm in size) was applied as a coarse aggregate with an apparent density of 2740 kg/m^3. The aggregate mix proportions were also key to improving the packing density of concrete [24]. Fuller curve was based on defining conventional concrete dosages by selecting coarse and fine aggregate proportions according to the adjustment within the standard curve that allows for the maximum compaction of granular elements, which is the method that corresponds to the Gessner parabola [25]. Since the Fuller curve was proposed, it has been used for designing concrete mixes for many applications, particularly for those of high-density and high-performance concrete [26–28]. The Fuller curve is a series of curves, widely used for the optimization of concrete aggregates, and expressed as:

$$U(j) = 100 \times (j/D_{\max})^h \qquad (1)$$

where $U(j)$ is the total volume percent of particles passing through a sieve, (in %); $D_{\max}$ is the maximal size of the aggregate, (in mm); j is the diameter of the particular sieve, (in mm); and h is the exponent of the equation.

The value for h, which varies from 0.33 to 0.45, was selected as 0.33 [26,29] in this study. The mass ratios of aggregates of different particle size are given in Table 2, calculated using Eq. (1).

2.3. Methods

2.3.1. Concrete samples preparation

The concrete samples were made according to Chinese national standard for testing fresh concrete GB/T50080-2002 [30] (equivalent to ASTM C192M-02). All concrete samples, measured 100 mm × 100 mm × 100 mm, were cured at 20 ± 2 °C in molds for the first 24 h, then demoulded and cured in an environment of 20 ± 2 °C and at 95 ± 5% RH until the day of testing.

2.3.2. Compressive strength test

The compressive strength test of concrete was carried out according to the Chinese national standard for testing mechanical properties of concrete GB/T 50081-2002 [31] (equivalent to ASTM C39). The compressive strength of concrete was evaluated for the ages of 1, 3 and 28 days at a loading rate of 0.5 MPa/s as per GB/T 50081-2002.

2.3.3. Electrical resistance test

In this study, the concrete was mixed with a water-binder ratio (0.25, 0.30 and 0.35) and cast into 100 mm^3 cubes for the electrical resistance test. The negative and positive copper electrodes were placed parallel to each other inside the cubic concrete samples, and the average testing results of the three samples were taken as the representative value. The schematic diagram of the concrete specimen prepared for electrical resistivity measurement is shown in Fig. 1.

2.3.4. Sulfate attack resistance

The resistance of concrete to sulfate attack was conducted according to Chinese national standard for testing durability of concrete GB/T 50082-2009 [32] (equivalent to ASTM C 1012). The solution was made by dissolving reagent grade sodium sulfate (Na_2SO_4) in deionized water and contained a final SO_4^{2-} concentration of 33,800 ppm (i.e. 5% Na_2SO_4). All specimens were stored in plastic containers having the solution with ample space between them. The containers with the specimens were stored in a constant temperature (20 ± 1 °C) room and the solutions were replenished periodically once a week to remain the designated concentration. Other control concrete cubes were kept in deionized water as well. The degree of sulfate attack was evaluated by measuring the compressive strength of concrete samples at 28 days, and the ratio of compressive strength was calculated by Eq. (2) as follows:

$$K_f = \frac{f_{cn}}{f_{c0}} \qquad (2)$$

where, K_f is the compressive strength ratio, (in %); f_{c0} is the average compressive strength (in MPa) of the control concrete cubes cured for 28 days in deionized water; and f_{cn} is the average compressive strength (in MPa) of three concrete cubes immersed in 5% sodium sulfate solution for 28 days.

3. Dosage of cementitious materials

3.1. Packing model of concrete

According to classical concrete mixture proportion design, the aggregates are considered the main skeleton of concrete and the paste requirements for workable concrete are determined by the aggregate gradation. Effective packing can be attained by selecting accurate proportions of small size particles to fill in the

Table 1
Chemical composition of raw materials (wt.%).

Materials	SiO_2	Al_2O_3	CaO	MgO	SO_3	Fe_2O_3	Other	Loss
Sulphoaluminate cement	11.41	27.87	43.86	–	10.73	2.59	2.38	1.16
Fly ash	50.55	29.01	6.00	5.44	3.65	–	4.12	2.08
Slag powder	29.46	17.44	34.71	11.02	3.37	–	0.3	0.30