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Experimental study on segregation resistance of nanoSiO_2 fly ash lightweight aggregate concrete

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HIGHLIGHTS

- Fly ash gives LWAC mixture with higher fluidity.
- NanoSiO_2 improves segregation resistance of LWAC.
- Combined admixture of nanoSiO_2 and fly ash gives LWAC both higher fluidity and higher segregation resistance.
- LWAC with nanoSiO_2 and fly ash shows higher strength and lower brittleness.

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ABSTRACT

Lightweight aggregate concretes (LWACs) of strength grade raging from LC40 to LC50 were prepared by adding different proportions of fly ash and nanoSiO_2. Segregation resistance of LWAC was studied by slump and segregation degree tests. The results indicate that adding of finer fly ash enhances the fluidity of LWAC and enlarges the slump, meanwhile, with the increase of fly ash content, segregation degree of concrete is decreased and floating of lightweight aggregate is somewhat alleviative but still exists; adding of nanoSiO_2 improves the segregation resistance of LWAC to a certain extent, but deteriorates the fluidity of concrete mixture; combined admixture of nanoSiO_2 and fly ash not only increases the slump of LWAC, but also improves its segregation resistance, prevents the floating of lightweight aggregate and makes concrete show better homogeneity. Mechanical property tests indicate that combined admixture of nanoSiO_2 and fly ash improves the compressive strength, increases the tension–compression ratio and reduces the brittleness of concrete.

1. Introduction

Lightweight aggregate concrete (LWAC) can reduce the self-weight on the basis of ensuring effective strength, so as to increase the floor height and bridge span due to its light weight, high strength and high durability [1–2]. The density of LWAC is 25–40% smaller than ordinary concrete under the same conditions, so construction of various buildings using LWAC has good economic benefits and technology prospects [3–4]. However, since the densities of most lightweight aggregates are smaller than cement slurries, it makes concrete mixture segregate that the lightweight aggregates in LWAC are easy to float during the vibrating process and on the stationary state [5–6]. Additionally, that lightweight aggregate is easily absorbent in the mixing process due to its porous structure makes the slump of LWAC lose seriously [7]. Li and Ding have studied the effects of different aggregate types on segregation resistance of LWAC, and the results show that spherical ceramsite with smooth surface that floating easily has relative poor segregation resistance and the larger the ceramic particle size, the more obvious the floating phenomenon [8]. Wu, Zhang et al. have proposed self-compacting lightweight aggregate concrete technique to solve the floating problem of lightweight aggregate, and have designed two different mix proportions. It is proved that self-compacting lightweight aggregate concrete mixture has good workability and shows no segregation [9]. Chen and Liu have studied the effects of incorporation of different fibers on segregation resistance of LWAC, the results show that incorporation of fibers reduces the aggregate segregation and improves the integrity of LWAC mixture, but decreases the slump of mixture [10]. How to control the floating of aggregate in the condition of without restraining other properties of LWAC has been a hot point of academic research, and also a difficult point in engineering practice.

The emergence of nano-materials provides a new perspective to solve this problem [11–12]. In recent years, there are lots of researches on the application of nano-materials in concrete. For

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example, Bastami et al. have researched the high temperature properties of high strength concrete modified by nanoSiO_2, the results indicate that mechanical properties of concrete under high temperature can be improved by nano-materials, residual stress and tensile strength of concrete can be enhanced as well [13]. Yu et al. have studied the effect of nano-silica on the hydration of ultra-high performance concrete (UHPC) with a low binder amount, the results reveal that, on one hand, the retardation effect that dormant period of cement hydration is extended by superplasticizer can be significantly compensated by the nucleation effect of nano-silica, on the other hand, with the addition of nano-silica, the of UHPC significantly increases, which causes that more air is entrapped in the fresh mixtures and the porosity of the hardened concrete correspondingly increases [14]. Behfarnia and Salemi have studied the effects of nanoSiO_2 and nanoAl_2O_3 on frost resistance of normal concrete, experimental results show that the frost resistance of concrete containing nano-particles are considerably improved, and it is also concluded that the frost resistance of concrete containing nanoAl_2O_3 was better than that containing the same amount of nanoSiO_2 [15]. Shaikh and Supit have researched the mechanical and durability properties of high volume fly ash concrete containing nano$CaCO_3$, and results reveal that the addition of nano$CaCO_3$ not only leads to much denser microstructure in HVFA matrix but also changes the formation of hydration products, hence contributes to the improvement of early-age compressive strength and durability properties of HVFA concretes [16]. However, the study about effect of nano-material and fly ash on segregation resistance of LWAC is still not seen.

Hence, this paper presents the LWACs of strength grade raging from LC40 to LC50 by adding different proportions of fly ash and nanoSiO_2, studies the influence laws on segregation resistance and mechanical properties of LWAC in the aspects of fly ash content and nanoSiO_2 content, and provides a theoretical basis for improving the workability of LWAC in engineering application.

2. Experiment

2.1. Raw materials

The cement used in this study is Ordinary Portland Cement (OPC) PO42.5 with specific surface area of 330 m^2/kg, provided by Huaxin Cement (Zhuzhou) Co. Ltd. Fly ash (FA) is offered by Hunan Xiangtan power plant with specific surface area of 425 m^2/kg. NanoSiO_2 (NS, as shown in Fig. 1) used is produced by Jinhe nano-chemical industry (Shijiazhuang) Co. Ltd, and its specific surface area is 170 m^2/g. Coarse aggregate used is high-strength crushed shale ceramsite (as shown in Fig. 2) with continuous grain size of 5–20 mm, and its bulk density is 850 kg/m^3, apparent density is 1405 kg/m^3, measured cylinder compressive strength is 6.1 MPa, 1 h water absorption rate is 6%. Fine aggregate chosen is Xiang river sand with fineness modulus of 2.75, bulk density of 1480 kg/m^3, apparent density of 2650 kg/m^3. A naphthalene sulfonate based superplasticizer is used to adjust the workability of LWAC. The chemical components of used OPC and FA are shown in Table 1, respectively. Additionally, the chemical properties of nanoSiO_2 are shown in Table 2.

Fig. 1. NanoSiO_2.

Fig. 2. Crushed shale ceramsite.

Table 1
Chemical components (by mass) of cementitious materials %.

Material	SO_3	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
OPC	2.41	23.30	2.77	5.41	61.16	2.65	0.68	0.07
FA	0.42	50.25	5.35	34.20	4.50	1.50	1.20	0.80

2.2. Test methods

The slump test of fresh mixture of LWAC was carried out in accordance with Chinese standard GB/T 50080-2002 "test method of performance of ordinary concrete mixture".

The segregation degree test is to measure the weight difference of lightweight aggregate between upper layer and lower layer of segregation degree bucket after 20 s vibration. The segregation degree bucket consists of three conjoint cylindrical buckets with the diameter of 200 mm, height of 200 mm. When measured, the cement mortar is washed away and the lightweight aggregates are picked out then their dried weights are weighed. The formula of segregation degree is shown as follows:

$$SG = \frac{2(g_1 - g_2)}{(g_1 + g_2)} \times 100\% \quad (1)$$

where SG is the segregation degree (%), g_1 the weight of aggregate in upper layer (g), g_2 the weight of aggregate in lower layer (g).

The test of mechanical properties of LWAC was carried out in accordance with Chinese standard GB/T 50081-2002 "test method of mechanical properties of ordinary concrete". LWAC samples were cast in molds with the size of 100 mm × 100 mm × 100 mm. The specimens were demolded approximately 24 h after casting and then cured in standard curing room of temperature about (20 ± 3)°C. After curing for 7 and 28 days, the compressive strength and splitting tensile strength of the specimens were tested, respectively. Three specimens were tested at each age to compute the average strength.

2.3. Mix design of LWAC

Table 3 illustrates the details of mix proportions of LWAC containing different amounts of FA and/or NS as a replacement of cement. The water binder ratio was kept constant as 0.3 and three different proportions of FA (18%, 24%, and 30%) and/or NS (0.5%, 1.0%, and 2.0%) by weight of cement were used for production of LWAC mixes. The control concrete without FA and NS was fabricated along with above mixes.