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Effect of nano-SiO_2 on strength, shrinkage and cracking sensitivity of lightweight aggregate concrete

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HIGHLIGHTS

- The early compressive strength of LWAC was improved by adding nano-SiO_2.
- Nano-SiO_2 had no significant influence on the long-term shrinkage of LWAC.
- With nano-SiO_2 addition, LWAC reduces the cracking risk at the early age.
- The simplified models for the compressive strength and shrinkage are proposed.

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ABSTRACT

This paper presents an experimental investigation on the effect of nano-SiO_2 on the compressive strength, shrinkage and early cracking sensitivity of lightweight aggregate concrete (LWAC). Two types of ceramsite with different water absorption were used as lightweight aggregate in this study. LWAC with different nano-SiO_2 dosage (1%, 2%, 3%) were compared with the reference LWAC to assess the effects of nano-SiO_2 on LWAC. Results revealed that the incorporation of 3% nano-SiO_2 increased compressive strength of LWAC significantly while the influence of nano-SiO_2 on the long-term shrinkage of LWAC was not significant. The total cracking area was decreased with the increase in nano-SiO_2 dosages from 1% to 3% by mass of the total binders at early age. The results of scanning electron microscopy (SEM) showed that the interfacial transition zone (ITZ) between lightweight aggregate and paste was enhanced with 3% nano-SiO_2 addition. Subsequently, simplified models for compressive strength and shrinkage of LWAC were proposed and a comparison between the experimental data and models was discussed.

1. Introductions

In recent years, the development of lightweight aggregate concrete (LWAC) has drawn increasing attention from researchers and engineers. Compared with normal weight concrete, reducing construction costs by decreasing structural dead load and lower thermal conductivity make LWAC increasingly used for housing, bridges and other construction projects [1–3]. However, the properties of lightweight aggregates used in LWAC vary within wide limits and the aggregates exert an important influence on the elastic modulus of concrete [4,5]. Generally speaking, lightweight aggregates have a lower strength and elastic modulus than the mortar matrix and, therefore, than normal weight concrete [6]. The low compressive strength and low elastic modulus of LWAC are often considered as a major shortcoming [2,5] except for some special applications.

In order to compensate this deficiency, improve the strength and durability of LWAC and reduce the cement consumption, more and more attentions have been paid on the mineral additions. Similar to normal weight concrete, LWAC can be effectively modified by adding supplementary cementitious materials (SCMs), which can improve the mechanical and durability properties of concrete. Previous studies found that the bulk properties of LWAC might be able to be modified with SCMs addition, such as silica fume [7,8], fly ash [9–11], ground granulated blast furnace slag [12–14] and metakaolin [15,16]. Among these SCMs, silica fume has been proved to be the most effective SCM for the performance enhancement of LWAC [12,16,17]. As a pozzolanic material, silica fume reacts with $Ca(OH)_2$ and produces additional calcium silicate hydrate (C-S-H) gel, which results in a denser microstructure and thereby improving the properties of hardened cementitious materials [18,19]. In general, the improvements were mainly attributed

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to the pozzolanic reaction, as well as the acceleration effect of silica fume on cement hydration and optimizing particle packing of the matrix [17,19,20].

More recently, some studies [21–25] reported that the properties of cement-based materials can be modified effectively by using nano-particles such as nano-SiO_2, which has a higher pozzolanic activity than silica fume. A common characteristic of silica fume and nano-SiO_2 is that they are both pozzolanic materials which contain over 90% SiO_2 (by weight). Ye et al. [26] reported that 3% nano-SiO_2 improves the ITZ more effectively than silica fume by digesting $Ca(OH)_2$ crystals, decreasing the orientation of $Ca(OH)_2$ crystals and reducing the crystal size of $Ca(OH)_2$ gathered at the ITZ. Some results [8,27–29] have shown that silica fume could improve the strength and durability of LWAC obviously. Interface bonding between hardened cement paste and lightweight aggregate is improved on account of better packing and pozzolanic reaction [28]. Until now, few studies [21,30] have investigated the effects of nano-SiO_2 on the performance of LWAC.

In this paper, the effects of nano-SiO_2 on the compressive strength, shrinkage and early cracking sensitivity of LWAC were investigated. The effects of nano-SiO_2 on microstructure of LWAC at 28 days were also studied. In addition to the experimental work, simplified models by modifying the ACI-209 model were established by using the experimental results. Moreover, the experimental data was also compared with the model curve in terms of the compressive strength and the shrinkage of LWAC.

2. Experimental

2.1. Materials

Two types of ceramsite with different water absorption were used as lightweight aggregate in this study. Ceramsite N (fly ash-clay ceramsite) was made in Nantong, China while Ceramsite Y (shale ceramsite) originated from Yichang, China. Main properties of the two ceramsites are given in Table 1, including two different densities. The apparent density and bulk density (GB/T 17431.2-2010) [31–33] of ceramsite N are 1064.5 kg/m^3 and 585.0 kg/m^3, respectively, while those of ceramsite Y are 1209.1 kg/m^3 and 635.8 kg/m^3, respectively. The practicality picture of lightweight aggregate and the SEM images of their pore structures are shown in Fig. 1. The particle size distribution of aggregates used in this study is given in Fig. 2. Amorphous nano-SiO_2 was produced by

Table 1
Physical properties of ceramsite.

Type	Ceramsite	Cylinder compressive strength (MPa)	Apparent density (kg/m^3)	Water absorption 1 h/24 h (%)	Bulk density (kg/m^3)
1	N (Nantong)	4.63	1064.5	9.10/12.70	585.0
2	Y (Yichang)	11.66	1209.1	3.34/5.74	635.8

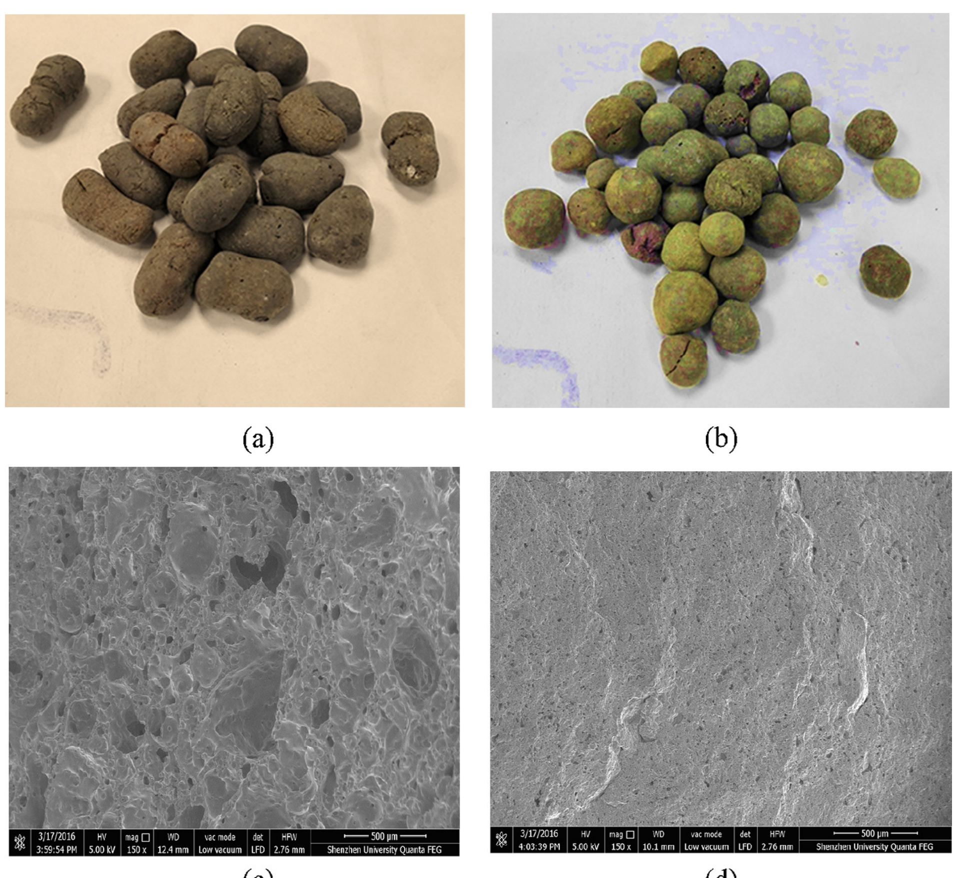

Fig. 1. Two types of ceramsite used in this study: (a) ceramsite N; (b) ceramsite Y; (c) SEM image of ceramsite N; (d) SEM image of ceramsite Y.