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The synergistic effect of nano-silica with blast furnace slag in cement based materials

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HIGHLIGHTS

- Nano-silica has a negative effect on the hydration of BFS.
- Nano-silica enhances the compressive strength of cement matrix with BFS.
- Nano-silica and BFS significantly reduce the porosity of the cement matrix.

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ABSTRACT

The synergistic effect of nano-silica (NS) and blast furnace slag (BFS) have been studied. A constant water-to-binder ratio (w/b) of 0.5 was used for all mortars. The different dosage (10%, 20%, 30% and 40%wt) of BFS and 3%wt NS were added into cement. The results indicated that comparing with the reference BFS mortars without silica inclusion, incorporation of a small amount of NS in cement containing BFS increased 28 days compressive strength, significantly. The incorporation of 3%wt NS in the cement pastes with 30%wt dosage of BFS have the highest compressive strength (59.42 MPa). In the work, the heat of hydration, non-evaporable water content and pozzolanic activity of BFS were studied, and the results showed that NS has a negative effect on the hydration of BFS; Through the analysis of the total porosity and the pore size distribution, NS and BFS can significantly reduce the porosity of the cement matrix, and increase the density, which is also an explanation of the phenomenon of increased compressive strength.

1. Introduction

Blast furnace slag (BFS) as supplementary cementitious material has been widely applied to concrete construction for the economic benefits and environmental benefits. Moreover, the pozzolanic effect and physical effect of BFS granules can further enhance the workability, mechanical strength and durability of concrete [1–4]. In recent years, many studies have found that the utilization of nano-silica (NS) in cement based materials can significantly improve the properties in hardened state. The research of Land et al. [5] shows that when nano-silica is added into the C_3S, C-S-H-seeds described by Thomas et al. [6] are formed on the silica surface by an early pozzolanic reaction to accelerate the hydration of C_3S. Jo et al. [7] found that adding 3%wt. of NS can greatly improve the strength of mortar. The research of Nazari et al. [8–10] shows that NS can decrease the total porosity of concrete mixture, and transform the harmful hole into harmless or less harmful hole, which can obviously improve the pore structure of hardened concrete; Results from Ji et al. [11] prove that the NS can promote the impermeability and frost thawing resistance of concrete by improving the inside pore structure. Thus, the roles of the NS are summarized as follows:

(i) NS not only act as fillers to improve the microstructure, but also as an activator to promote pozzolanic reactions [12].
(ii) NS act as a nucleation site for C-S-H seeds which then accelerate the cement hydration [5].
(iii) NS accelerates the hydration of C_3S and the formation of portlandite (small sized CH) crystals and homogeneous clusters of C-S-H composition [5].

Zhang et al. [13,14] found that use of nano-silica can reduce setting time and increase early strength of concrete with high volume slag. But for the interaction between nano-silica and BFS, they did not give a clear explanation. According to report in the literature [5,12,15], we can conclude that nano-silica and BFS can regulate

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the microstructure and properties of the cementitious materials in the smaller scale by making full use of the synergistic effect of filling effect, nucleating effect and activity effect between them, which would achieve a substantial increase in the performance of cementitious materials.

This paper presents an experimental study on the synergistic effect between nano-silica and blast furnace slag. Nano-silica with a specific surface of 300 m^2/g was used in the study. The compressive strength, heat of hydration, pozzolanic activity of BFS and pore size distribution were used to illustrate the synergistic effect.

2. Raw materials and methods

In this study, the compressive strength of mortars with varied dosages of NS and BFS in 3 days, 7 days and 28 days were tested to determine the interactions of NS and BFS. A constant water-to-binder ratio (w/b) of 0.5 was used for all mortars. To avoid the influence of aggregate on analyzing hydration properties and pore structure of cement matrix, the cement paste with w/b ratio of 0.4 was prepared. And 0.7 w/b were prepared to determine the rate of heat development and cement hydration in the first 72 h. Naphthalene water reducer was used to attain a certain fluidity of cement mortar in the experiment [16–18].

Table 1
Physical properties and chemical compositions of materials.

		Portland cement	Blast furnace slag	Nano-silica
Chemical compositions (%)	CaO	60.1	35.53	–
	SiO_2	21.37	32.31	>99.8[a]
	Al_2O_3	5.67	16.36	–
	MgO	3.94	10.41	–
	Fe_2O_3	3.09	0.29	–
	SO_3	2.65	2.74	–
	LOI	3.18	2.56	–
Physical properties	Surface area(m^2/kg)	310	380	300000[a]
	Average primary particle size	20.4 μm	13.96 μm	7–40nm[a]
Compressive Strength/MPa	3d	32.43	–	–
	28d	52.43	–	–
Activity Index (%)		–	103.6	–

[a] Information provided by supplier.

2.1. Raw materials

Ordinary Portland cement (OPC) was obtained from SUNNSY Group Cement Plant. BFS with 380 m^2/kg fineness were used in this study. Hydrophilic-300 nano silica dioxide come from Aladdin Industrial Corporation were used. The chemical compositions and physical properties of the ingredients are presented in Table 1. Scanning electron microscopic image of Nano-silica was shown in Fig. 1. In order to meet the working performance, naphthalene water reducer was used in this study. ISO standard sand was used to make mortars.

2.2. Mixture ratio

The mixture ratios of BFS with different dosage are shown in Table 2. All mortars with a water to cement ratio of 0.5 and cement to sand ratio of 3.0 were used in this work. The 3%wt nano-silica and different dosages (10%, 20%, 30% and 40%) of the BFS were added into cement to investigate the synergistic effect between nano-silica and BFS.

2.3. Mixing of the sample

In order to solve the problem of aggregation of nano-silica, the pre-process method of ultrasonic dispersion was adopted. And the

Table 2
Mix proportions of slag mortars with nano-silica with specific surface area of 300 m^2/g (w/b = 0.5).

Mix ID	Cement/g	w/b/%	BFS/%	Nano-silica/%	Sand/g	Super-plasticizer[a]/%
Control	450	0.5	0	0	1350	0
10BFS	450	0.5	10	0	1350	0
20BFS	405	0.5	20	0	1350	0
30BFS	360	0.5	30	0	1350	0
40BFS	315	0.5	40	0	1350	0
NS	270	0.5	0	3	1350	2.5
10BFS+NS	391.5	0.5	10	3	1350	2.5
20BFS+NS	346.5	0.5	20	3	1350	2.5
30BFS+NS	301.5	0.5	30	3	1350	2.5
40BFS+NS	256.5	0.5	40	3	1350	2.5

[a] % of (cement + slag + nano-inclusion) by mass.

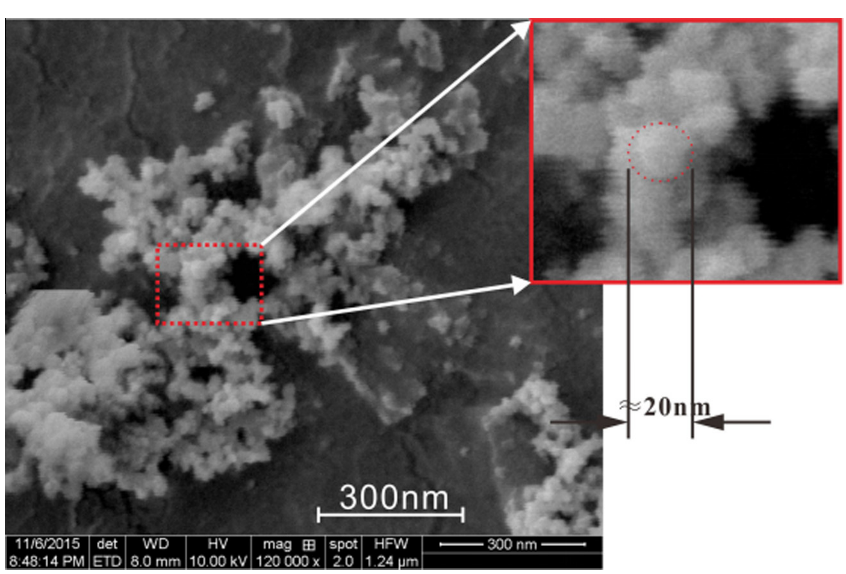

Fig. 1. Scanning electron microscopic images of nano-silica.