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Microstructure characteristics of cement-stabilized sandy soil using nanosilica

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ABSTRACT

An experimental program was conducted to explore the impact of nanosilica on the microstructure and mechanical characteristics of cemented sandy soil. Cement agent included Portland cement type II. Cement content was 6% by weight of the sandy soil. Nanosilica was added in percentages of 0%, 4%, 8% and 12% by weight of cement. Cylindrical samples were prepared with relative density of 80% and optimum water content and cured for 7 d, 28 d and 90 d. Microstructure characteristics of cement-nanosilica-sand mixtures after 90 d of curing have been explored using atomic force microscopy (AFM), scanning electron microscopy (SEM) and X-ray diffraction (XRD) tests. Effects of curing time on microstructure properties of cemented sandy soil samples with 0% and 8% nanosilica have been investigated using SEM test. Unconfined compression test (for all curing times) and compaction test were also performed. The SEM and AFM tests results showed that nanosilica contributes to enhancement of cemented sandy soil through yielding denser, more uniform structure. The XRD test demonstrated that the inclusion of nanosilica in the cemented soil increases the intensity of the calcium silicate hydrate (CSH) peak and decreases the intensity of the calcium hydroxide (CH) peak. The results showed that adding optimum percentages of nanosilica to cement-stabilized sandy soil enhances its mechanical and microstructure properties.

1. Introduction

Soil treatment with cement agents (e.g. lime, gypsum, Portland cement, and fly ash) has been a ground improvement technique in foundation engineering, road construction, and geotechnical engineering for many years (Choobbasti et al., 2014; Kutanaei and Choobbasti, 2015a,b; Sarokolayi et al., 2015a,b; Tavakoli and Kutanaei, 2015; Mashhadban et al., 2016a). Cementation of sandy soil can result in increasing stiffness, shear strength, compressive strength, and brittle behavior and decreasing compressibility and permeability of the material (Kutanaei and Choobbasti, 2016a; Mashhadban et al., 2016b). The mechanical behavior of cement-treated soil has been explored in the past by several researchers. A number of researches have been performed to investigate the mechanical properties of cement-treated sandy soil using added zeolite, glass, fiber, fly ash, and silica fume in the same manner.

Mola-Abasi and Shooshpasha (2016) investigated the effect of zeolite content on mechanical properties of cemented sandy soil. They found an improvement of compressive strength of cement-treated sandy soil when the cement is replaced by zeolite at an optimum proportion of 30% after 28 d. Al-Swaidani et al. (2016) explored the influence of adding natural pozzolana on geotechnical characteristics of lime-treated clay. The results showed that the geotechnical properties of lime-treated clay are significantly improved when the lime is replaced by natural pozzolana at proportion of 20%. Changizi and Haddad (2015) conducted a series of unconfined compression tests and direct shear tests to explore the effects of nanosilica and fiber on the strength properties of soft clay. They found that the unconfined compressive strength (UCS) and cohesion of clay increase with the increasing nanosilica content.

Limited studies have reported the use of pozzolana such as nanoparticles. The use of nanosilica as cement-based material modifier becomes more popular due to a more satisfactory performance compared with conventional modifiers (e.g. microsilica). Ghazi et al. (2011) performed the unconfined compression tests to study the strength improvement of clay stabilized with 6% cement due to the inclusion of nanosilica. They found that by adding 2%

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nanosilica, strength is increased from 1.7 MPa to 2.1 MPa. Bahmani et al. (2014) explored the influence of nanosilica particles on the UCS, hydraulic conductivity, and Atterberg limits of cemented clay. They reported that inclusion of nanosilica particles leads to a reduction in plasticity index and an improvement in soil strength. Ghasabkolaei et al. (2016) performed unconfined compression tests and California bearing ratio (CBR) tests to explore the effect of nanoparticles on geotechnical properties of cement-stabilized clayey soil. They found that adding 1.5% nanosilica improves the UCS of the cemented clay. Choobbasti et al. (2015) conducted a series of unconfined compression tests to investigate the mechanical properties of sandy soils stabilized with Portland cement and nanoparticles. They found that the UCS increases with increase in nanosilica content. Kutanaei and Choobbasti (2016a) explored combined impacts of randomly distributed fibers and nanosilica on durability and mechanical characteristics of cement-treated sandy soils. They reported an optimum percentage for the nanoparticles in which the behavior of cement-treated sandy soils reinforced by randomly distributed fiber is improved significantly. Papatzani et al. (2014) investigated the impact of the inclusion of nanosilica on the microstructure characteristics and strength of blended Portland cement pastes. They reported that the microstructure properties of cement paste are improved with adding nanosilica. Papatzani (2016) investigated the impact of nanoparticles on cement hydration. The results showed that the chemical reactivity and durability of the nano-modified cement product are remarkably altered compared to cement pastes. Therefore, nanoparticles can improve the properties of cement.

Review of the literature relating to the mixture of nanosilica and cemented sandy soil shows that no attention has been paid to the use of nanosilica on microstructure of sandy soil. Hence, this research aims to quantify the impacts of the percentage of nanosilica and curing period on the microstructure and UCS of the cement-treated sandy soil. Unconfined compression tests and compaction tests are conducted and the impacts of these variables on the results are investigated. Microstructure characteristics of cement-treated sandy soil with nanoparticles are explored using atomic force microscopy (AFM), scanning electron microscopy (SEM) and X-ray diffraction (XRD) tests.

2. Experimental program

Twelve unconfined compression tests, 4 compaction tests, 8 SEM tests, 4 AFM tests and 4 XRD tests were performed to investigate the effects of nanosilica on the performance of cement-treated sandy soil.

2.1. Materials

Babolsar sand was used in this study. The particle size distribution curve for Babolsar sand is shown in Fig. 1. The ordinary Portland cement of type II was used as cement agent. Its chemical and physico-mechanical characteristics are presented in Tables 1 and 2, respectively. Nanosilica with a solid content of more than 99% was used. Physical characteristics of nanosilica particles are presented in Table 3. Distilled water was used for sample preparation.

2.2. Sample preparation

The undercompaction technique was used for sample (52 mm in diameter and 104 mm in height) preparation in this study based on the method described by Ladd (1978). The requisite amount of oven-dried sand was mixed with the desired amount of Portland cement and nanosilica until uniform color of mixture was achieved (about 30 min), and then the water equal to the optimum water content was added continuously to the mixture and mixed for about 20 min. After mixing process, the mixture was then divided into five portions and stored in a covered container to avoid moisture losses before compaction. Each portion was transferred into a 52 mm in diameter by 104 mm in height split mold and compacted using a metal hammer until the desired height was reached. The top of each layer was scratched before adding the next layer to promote suitable bonding. To control the homogeneity of sample density along height, one sample (for each mixture) was cut by a narrow saw wire at four positions, and the density of each piece has been determined and then the standard division was calculated. The standard division was 0.06 which showed good homogeneity of density. The tests were conducted on the samples with relative density of 80%. Each sample was cured in a humid room at a constant temperature of (25 ± 2) °C and relative humidity of >90% for 7 d, 28 d and 90 d. Before tests, the samples were submerged in distilled water for 1 d for saturation to minimize matric suction. Immediately before the unconfined compression test and microstructure imaging, the samples were removed from the water container and dried with an absorbent cloth.

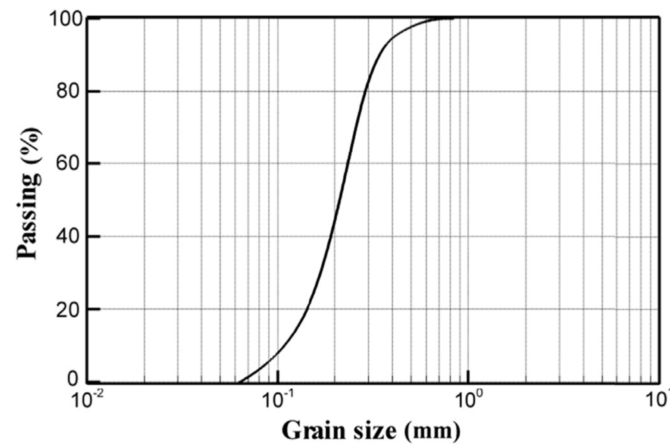

Fig. 1. Particle size distribution curve for Babolsar sand.

Table 1
Chemical compositions of ordinary Portland cement (percentage by weight of cement, wt%).

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	$CaCO_3$	Loss on ignition
21.9	4.86	3.3	63.33	1.15	2.1	–	2.4

Table 2
Physico-mechanical properties of cement.

Blaine fineness (cm^2/g)	Expansion (autoclave) (%)	Specific gravity	UCS (MPa)		
			3 d	7 d	28 d
3050	0.05	3.1	18.1	28.9	38.9

Table 3
Physical properties of nanosilica particles.

Diameter (nm)	Specific surface area (m^2/g)	Density (g/cm^3)	Purity (%)	Shape
20–40	193	1.7	>99	White powder