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Mechanical Properties of Sandy Soil Improved with Cement and Nanosilica

Abstract: In the literature, studies show that nanosilica particles and artificial pozzolans possessing can improve structural properties of cement-based materials. This paper studies the effect of cement and nanosilica on the engineering properties (compaction, unconfined compressive strength) of sand. Three different cement ratios (5, 9, and 14% by weight of dry sand) were mixed with four different nano silica ratios (0, 5, 10, and 15% by weight of cement), and then compacted into a cylindrical specimen. The results of the study presented that the addition of the cement and nanosilica improves the engineering properties of sands. The increase of maximum dry unit weight of sand was noted with the increase in the cement content. The presence of nanosilica in optimal percentages can significantly improve the mechanical properties of cement sand.

Keywords: Sand, Cement, Nanosilica, Unconfined Compressive Strength, Compaction

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1 Introduction

A man does not have any control over the process of soil formation. Existing soil on a given site may not be suitable for supporting the desired facilities [1–4]. Recently soil improvements became an attractive topic for engineers [5–7]. Various attempts have been made to improve the strength of soils using different chemical additives in combination with lime and cement. Recent trend in research works in the field of geotechnical engineering and construction materials focuses more on the search for cheaper and locally available material [8, 9]. The geotechnical and pavement engineering fields are attracting increasing interest in exploring soil improvement schemes that are based on the addition of stabilizing agents such as cementing agents for various applications.

Usually, cement is used as soil stabilizing agent especially for road construction, such as for sub base [10, 11]. Portland cement is the most important hydraulic cement utilized extensively in various types of cement stabilization of lateritic soils. Cement acts as a binder and provides desired hardening and strengthening properties. The addition of cement also increases the compressive strength, the resistance of lateritic soils to freezing; wetting and drying [12]. Ali and Youssef reported that the cement used as a subgrade material in Saudi Arabia is intended to stabilize sandy silt [13]. Ansary et al. investigated the use of fly ash in order to verify the strength of stabilized soils. In their study, unconfined compressive strength, compaction properties and flexural properties were examined. Fly ash with lime constituted the admixture. The amount of lime was fixed at 3%, while amounts of fly ash were 0%, 6%, 12% and 18%. The results showed that by increasing the amount of fly ash the strength properties of lime–fly ash stabilized soils were improved [14]. Das also reported that the usage of cement stabilization improves the shear strength of sand [15]. Ramana Sastry and Srinivas noticed that the stabilized base reduces the deflection at the joints to such an extent that load transfer devices are no longer necessary [16]. Oyediran et al. while investigating the influence of termite activities of clay with higher cement content behaves like a soft rock. Based on results, when it comes to the geotechnical properties of some lateritic soils, they concluded that the termite reworked soils showed remarkable improvement in shear strength, CBR, plasticity index and specific gravity [17]. Lee et al. (2001) reported that the behavior of the cement-clay with lower cement content is similar to an over-consolidated soil. They also introduced a constitutive model for cement-clay with a new parameter (bonding stress ratio) to account for the effect of cementation within the framework of the critical state concept [18].

Recently, advances in nanosciences and nanotechnologies have made it possible to use nanoparticles in soil stabilization. A nanoparticle is defined as a particle that has

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at least one dimension at the nanometer scale (i.e., 1 nm to 100 nm) [19, 20]. It seems that in the near future significant developments will be observed in cement technology thanks to the introduction of nanosilica with high purity and a finer particle size. Studies have shown that the application of nanosilica into the production of cement based material can improve its mechanical properties and abrasion resistance [21–24]. The rate of pozzolanic reaction is proportional to the amount of surface available for reaction (owing to the high specific surface of nano particles). They possess high pozzolanic activity and consume calcium hydroxide, which arrays in the interfacial transition zone between hardened cement paste and aggregates. They also produce hydrated calcium silicate which enhances the strength of cement paste [25]. In addition, it has been found that when the small particles of nanoparticles uniformly disperse in the paste, due to their high activity, a large number of nucleation sites for the precipitation of the hydration products are generated, accelerating cement hydration [26, 27]. Ghazi et al. investigated the effect of nanosilica addition on compressive strength of clay stabilized with 6% cement. The results showed that significant increase in strength of the specimens containing 0.5, 1 and 2% nanosilica was noted. Addition of 2% of nanosilica increased the strength from 1645 to 2346 kPa [28].
In this study the experimental survey focused on combined effect of cement and nanosilica on the engineering properties of sand. Three different cement ratios (5, 9, and 14% by weight of dry sand) and four different nanosilica ratios (0, 5, 10, and 15% by weight of cement) were considered.

2 Materials and mixing method

2.1 Sand

The sand used in the present study was collected from Khazar coastal area in Iran. Khazar coastal sand with a mean grain size, D_{50} = 0.221 mm, coefficient of uniformity, $C_u = D_{60}/D_{10}$ = 2.128, coefficient of gradation, C_c = 1.322, maximum and minimum void ratio, e_{max} = 0.8, e_{min} = 0.526 and specific gravity G_s = 2.78 have been used in this study. The grain size distribution of the sand is shown in Figure 1.

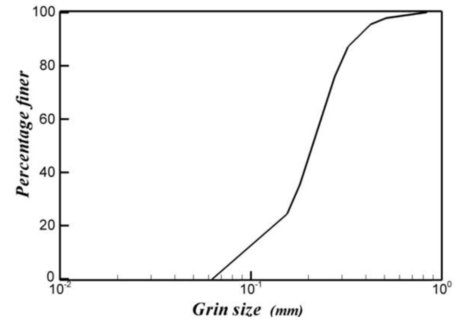


Figure 1: Particle size distribution.

Table 1: Chemical properties of the cement.

Chemical name	Percent (%)
SiO_2	21.25
Al_2O_3	21.25
Fe_2O_3	3.19
K_2o	0.63
Cao	64.07
Mgo	1.20
SO_3	2.04
NaO_3	3.08

2.2 Cement

The cement used in the study was ordinary Portland cement type II. It was obtained from cement company in Iran. This cement is the most widely used in the construction. The chemical properties of cement are presented in Table 1.

2.3 Nanosilica

In this study, amorphous nanosilica with a solid content of more than 99% was applied. The physical properties of these particles are presented in Table 2.

Table 2: Physical properties of nanosilica.

Physical properties	Value
Diameter (nm)	20 – 30
Surface volume ratio (m^2/g)	193
Density (g/cm^3)	1.7
1.7 Purity (%)	>99

2.4 Mixing method

In order to match the proper conditions and increasing the accuracy of test results, consistent mixing method was used for all specimens. Firstly, cement and nanosilica were mixed well in order to prepare specimens. Then, they were added to sand and mixed for 15 min. At the end, water was added to the mixture and mixed for 15 min.

3 Laboratory tests

3.1 Compaction test

All the compactions involving moisture-density relationships and unconfined compressive strength were carried out with the use of energy derived from the standard Proctor based on ASTM D558. The standard Proctor Compactions were carried out using energy derived from a rammer of 2.5 kg mass falling through a height of 30 cm in a 1000 cm^3 mould. The soil was compacted in three layers, each receiving 25 blows.

3.2 Unconfined compressive strength test

The cylindrical specimens used in unconfined compressive strength test are of diameter 38.1 mm and height 76.2 mm. After compaction, the specimens were extruded from the mould and kept in the humidity room at constant temperature of 25±2°C. After curing, specimens were placed in a load frame machine driven strain controlled at 0.10% min and crushed until failure occurred. Specimens were cured for 7 days. Unconfined compressive strength test was conducted on the compacted specimens according to ASTM D2166.

4 Result and discussion

4.1 Compaction

Results on dry density versus water content for sand, sand mixed with cement, sand with cement and nanosilica shown in Figure 2 and Figure 3 present the results of the effect of cement content on maximum dry density and optimum moisture content of sand mixed with cement. As it can be seen in mentioned Figures, maximum dry unit weight of the sand-cement mixes increase with the increase in cement content. The increases in maximum dry

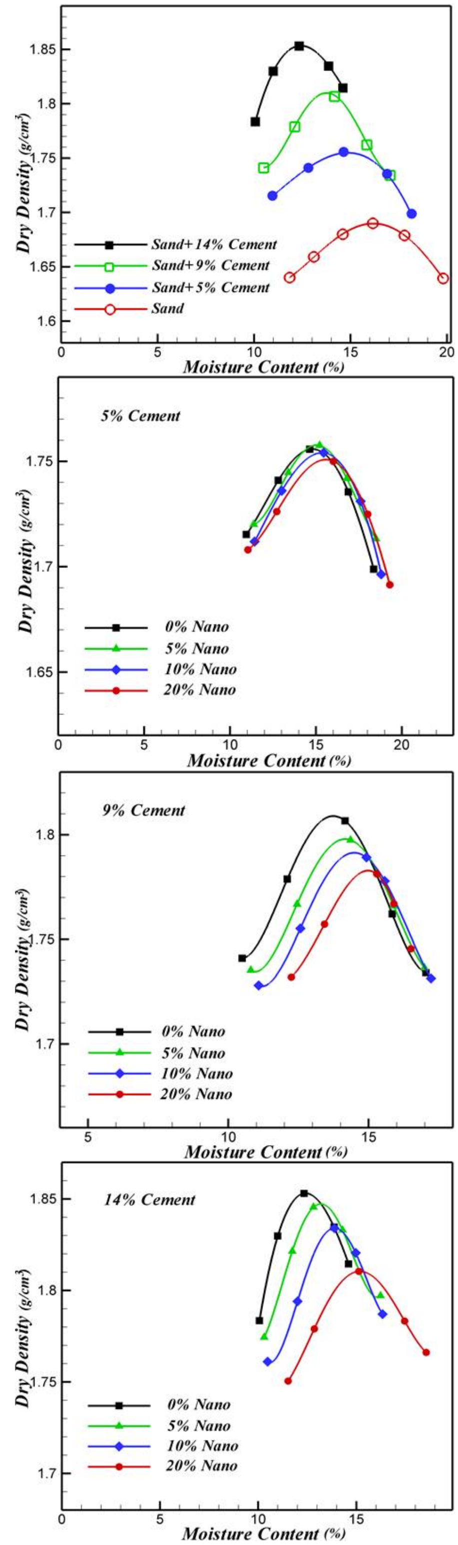
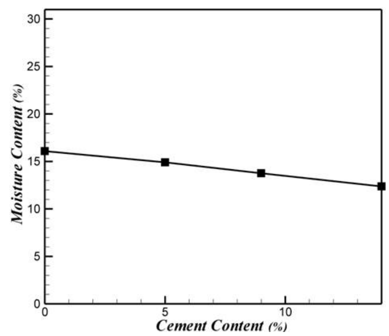


Figure 2: Compaction curves.

(a)



(b)

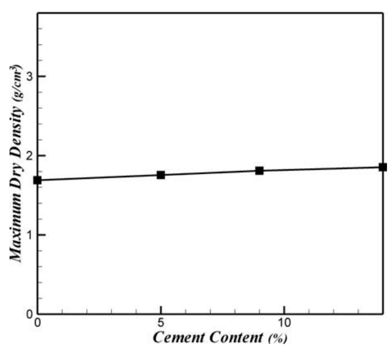
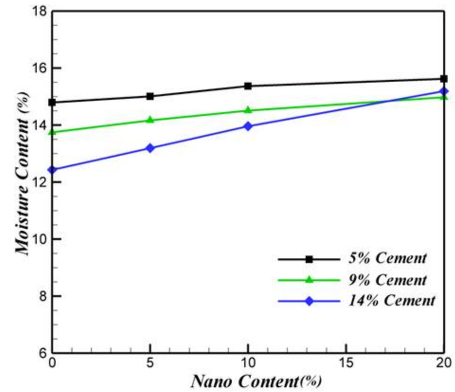


Figure 3: Effect of cement content on (a) optimum moisture content, (b) maximum dry density.

density of sand mixed with cement for standard Proctor Compaction can be attributed to the presence of large, high density aggregate particles. Figure 3(b) reveals that there is decreasing trend in the optimum moisture content of the sand-cement mixes with the increase in cement content. However, for all practical purposes it can generally be stated that the behaviour of sand-cement mixes and sand is very similar.

Figure 4 presents the results of the effect of nanosilica content on maximum dry density and optimum moisture content of sand with cement and nanosilica. Generally, there was an increase in the maximum dry density with increasing nanosilica content for low percentages of cement. It is due to the fact that the void within the coarse aggregate becoming occupied by nanosilica particles. In case of high percentages of cement, since nanosilica has a lower specific gravity (1.7) compared to sand (2.78) the maximum dry unit weight is decreased for higher percentages of nanosilica. As can be seen in Figure 4 the optimum moisture content of sand was found to increase with the increase in the nanosilica content. This is expected due to the fact that

(a)



(b)

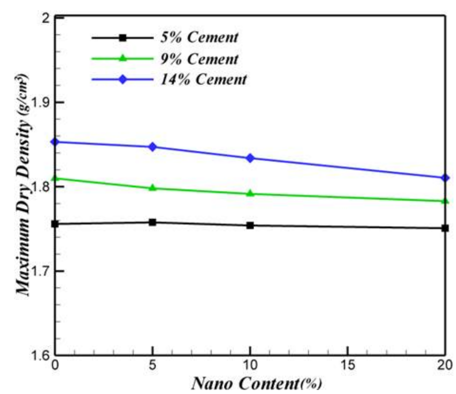


Figure 4: Effect of cement content on (a) optimum moisture content, (b) maximum dry density.

nanosilica has more specific area and will require more water to hydrate.

4.2 Unconfined compressive strength

The variation of unconfined compressive strength of cemented sand with nanosilica content is presented in Figure 5. It is obvious from this figure that the unconfined compressive strength increases significantly with cement content starting from a value 320 for 5% cement to 1763 kPa for 14% cement content. In all cement content, when nanosilica content increased to an optimum value of 10% in the sample, unconfined compressive strength of the sample was significantly improved. It can be seen that increasing the nanosilica content from 0% to 5% did not improved unconfined compressive strength significantly. It seems that a large amount of nanosilica (20%) even decreases the unconfined compressive strength. Accord-

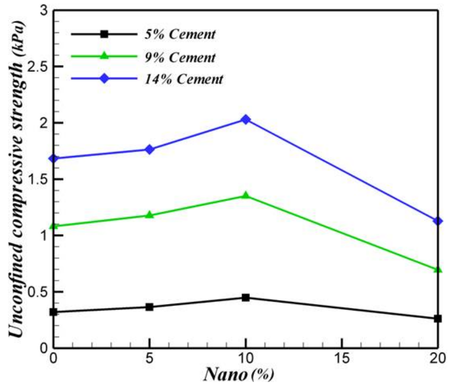


Figure 5: Effect of cement and nanosilica content on unconfined compressive strength.

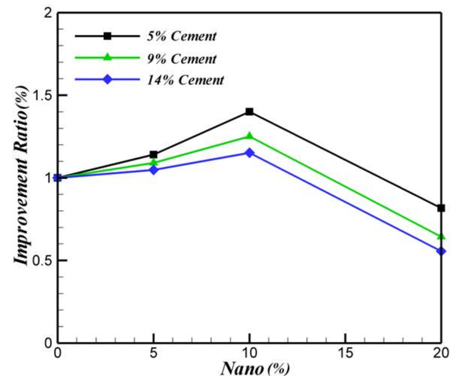


Figure 6: Effect of cement and nanosilica content on unconfined compressive strength improvement ratio.

ing to Hui li [22], homogeneous hydrated microstructure, which is essential for the strength of the cement matrix, cannot be formed because nano particles cannot be well dispersed. Strength enhancement of nanosilica can be attributed to the reduction in the content of $Ca(OH)_2$ which has no cementing property and produces no hydrated calcium silicate (CSH), which plays a vital role in the mechanical characteristics of cement paste [29, 30]. In the structure of the hydrated calcium silicate gel, nanoparticles can act like nucleus forming an extremely strong bond with hydrated calcium silicate gel particles and nanosilica. They can also generate a large number of nucleation sites for cement hydration products, making the paste microstructure more homogenous and improve its strength and durability [31].

For a more comprehensive presentation of the effectiveness of adding nanosilica on the unconfined compressive strength of the cemented sand, all results are presented in Figure 6 in terms of the ratio between the unconfined compressive strength of the cemented sand mixed with nanosilica to that of cemented sand without nanosilica. As can been seen in this figure for all percentages of nanosilica the sample containing 5% cement have higher improvement ratio than other cement content. This result shows nanosilica improves the unconfined compressive strength less for the samples with high cement content.

5 Conclusions

In this investigation the effect of cement and nanosilica on mechanical properties of sandy soils were investigated. From this investigation, the following conclusions are made:

1. The maximum dry density of sand increased with the increase in the cement content. There was an increase in the maximum dry density with increasing nanosilica content for low percentages of cement.
2. The optimum moisture content of cemented sand increased with the increase in the nanosilica content.
3. Increasing nanosilica content up to 10% cement content significantly increased the unconfined compressive strength of the samples. However, increasing of nanosilica content of the samples more than 10%, decreases the unconfined compressive strength. Optimal percentage of nanosilica for the stabilization of cemented sand was 10% cement content.

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