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Effect of Nanoparticles on Geotechnical Engineering Properties of Granular Soils by Using Injection Method

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Abstract

In most civil engineering projects, it is not possible to achieve an adequate site for satisfying all of the design needs, and therefore, it is necessary to improve the entire soil or part of it, using techniques such as substitution, etc. One widely-used technique for improving the engineering properties is the use of different additives, and it is worth noting that in the past, these additives included bitumen, lime, fly ash, etc. Among the newest of these additives, one can point to nanoparticles that cause an improvement in physical, mechanical, and in general, geotechnical properties. The aim of this research is to study the effect of two types of nanoparticles, namely, Nano silica and Nano Aluminum Oxide, on the compressive strength of poorly graded sand. To this end, different proportions of 0.3, 0.6, and 0.9 percent of the dry cement weight for each nanoparticle, homogenized with cement slurries with water to cement ratios of 1, 1/4, and 1/8, were injected into poorly graded sand with a relative density of 70% and a pressure of 2 bar. Based on the compressive strength in 7-day and 28-day samples, it can be understood that the samples' compressive strength increases with increasing the nanoparticles up to a certain point, and is stopped or reduced after this particular point. Furthermore, the effect of water to cement ratio on the samples' compressive strength is more than the effect of nanoparticles.

Keywords: Cement Injection, Compressive Strength, Nano Silica, Nano Alumina.

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Introduction

Nanotechnology includes the physical, chemical, and biological production and application of systems ranging in scale from a monoatomic or molecular area to submicron level, such as adding nanostructures to larger systems. Nanomaterials are defined as microstructures with at least one dimension in nanometer scale. The properties of nanoparticles include small size, grading distribution with a low level of agglomeration, and high release rate. These unique features of nanoparticles have caused nanotechnology to enter different sciences and solve the related problems. Fortunately, the science of geotechnical engineering is not an exception, and in the past few years a lot of efforts have been made to apply this new technology on different fields of geotechnics (Majdi, 2014). Most of the nanomaterials used for modifying the geotechnical properties of soils are Silica nanoparticles that affect soil characteristics such as stabilization, permeability index, and strength parameters. In 2005, Silica nanoparticles were used by Gallagher to increase soil cohesion and reduce its viscosity, and furthermore, the behavior of in cyclic loading conditions was analyzed. It was concluded that cohesion is dependent on the amount of increase in nanoparticles (P.M. Gallagher et al., 2007). In 2007, Patricia and colleagues in the US used nanomaterials in a special soil made of high-viscosity sand. Through applying an artificial earthquake and evaluating the settlement of soil, a 40% of improvement in soil settlement was obtained and it was shown that soil strength increases with the passage of time. Furthermore, it was found out that soils containing nanoparticles are formable in their early stages but their behavior is later changed to elastoplastic (C. Butron, 2009).

In general, the soil available for designing from an engineering perspective is not ideal and desirable for construction, and should therefore be prepared for specific purposes through making certain modifications. There are several approaches for making these modifications, the aim of which is to change the properties of a particular type of soil for the purpose of designing (Poorahmadi, 2014). These approaches are called soil improvement. Soil improvement is performed for improving the engineering function of soil in achieving different aims, and is described as a series of operations that leads to the elimination of undesirable behaviors of soil, and imposition of proper behaviors.

Among these, one can point to adding bitumen, lime, fly ash, etc. that can lead to a reduction in plasticity, and an improvement in density, strength, and stability of soil, and is usually used for fine grained soils. Furthermore, in granular soils, this can lead to a reduction in permeability and corrosion, and an increase in strength (D.F. Lin et al., 2006).

Using nanomaterials for soil improvement, controlling the strength characteristics of soil, and reducing the amount of cement used can be cost-effective. Moreover, nanomaterials benefit from some exclusive characteristics and their utilization in other engineering fields has led to principal changes in geotechnical engineering. Materials in nanoscale usually show different physical behaviors compared with atoms and bulk materials. The properties of nanoscale materials cannot be predicted based on the properties of materials in larger scales. Significant changes in the behavior of materials is not only caused by constant changes in the behavior of materials in smaller scales, but also is a result of the emergence of new phenomena such as quantum size limited and domination of the surface phenomena (Guoping Zhang, 2007). Using nanoparticles can lead to an improvement in the soil's mono-axis strength, an increase in its bearing power, and finally an increase in the bearing capacity of the foundation (Ghorbani, 2011). In the current research, the effect of nanoparticles (Nano Silica and Nano Alumina) on mono-axis strength of poorly graded sand is studied. Due to the fact that a comprehensive study of the effect of nanomaterials has not been done yet, this research can lead us to a better understanding of the effect of Nano Silica on soil, and therefore can be used as a further step towards using nanotechnology in geotechnical engineering.

Materials Used

Soil

The soil used for the purpose of this research was provided by Polad Insaat mine in Erzurum, Turkey. Selection of the samples was done based on the grading shown in Figure 1. Based on the USCS classification criteria, the soil used in this research is called fine grained poorly-graded sand (SP). Furthermore, the physical properties of the soil used in this research are shown in Table 1.

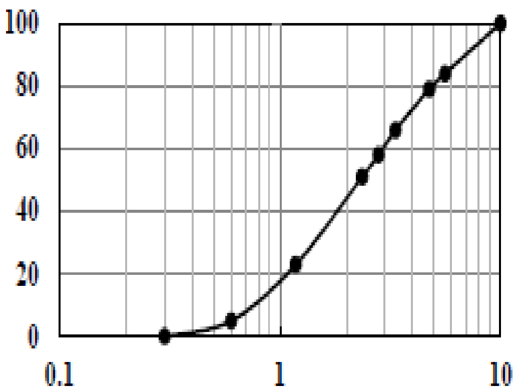

Fig. 1. The grading curve

Table 1. The physical properties of the soil in use

Gs	e_{min}	e_{max}	D_{10}	D_{30}	D_{60}	C_u	C_c	Soil	γ_{dmax}	γ_{dmin}	$\gamma_{d0.75}$	$\gamma_{d0.50}$
2.64	0.57	0.98	0.76	1.67	2.8	3.68	1.31	SP	1.68	1.33	1.58	1.48

Cement

The cement used in this research is the type 2 provided by Sufian cement factory, Tabriz, Iran, and corresponds with EN1971 standard. This cement type is mixed with combinations of lime CaO, Silicate SiO2, Aluminate Al2O3, and Iron Oxide. The size of a wet cement grain is approximately 10 micrometers, and its surface area to weight ratio is 0.3 that is increased up to 300 as a result of hydration (mixing water with cement) (Hami, 1992).

Silica Fume

It is a highly active pozzolanic material that easily reacts with CH and water, and is changed into C-S-H secondary form. The pozzolanic reaction of micro-silica can consume much of the CH, and the production of C-S-H fills the capillary cavities. This process in turn reduces the permeability of the concrete and decreases the possibility of CH reacting with other ions to form harmful products. Since micro-silica is twice smaller than Portland cement, it can easily fill the space between the cement grains. This material has a specific surface area of 20 and a density of 586. The silica fume used for the purpose of this research is provided by Iran's Pishgaman-e Nano Mavad Company.

Nano-silica

Silica is one of the most prominent materials that play a part in efficient cohesion and filling. A usual product is silica fume or micro silica with a diameter of 0.1 to 1 millimeter, and 90 percent of silica oxide. It can be said that micro silica is a product in the upper limit of nanometer size echelon, and is used to improve the efficiency of cementitious materials composite. Suspended Nano-silica has multiple functions such as:

- Anti-wear property
- Anti-slip property
- Flame retardancy property
- Anti-reflective property

All of the researches on the application of Nano-silica are done in areas such as the improvement of workability, and also rheological and mechanical properties. The primary result is Nano-silica with a diameter of 5 to 100 nanometers. Nano-silica causes an improvement in the density of particles. The Nano-silica used for the purpose of this research is provided by Iran's Pishgaman-e Nano Mavad Company.

Nano Aluminum Oxide

Nano alumina is a powder with the following properties that is provided by Iran's Pishgaman-e Nano Mavad Company. Phase stability, high degree of hardness, and materials with high dimensional stability are among the evident characteristics of this product. It is widely used in plastics and other strong products to maintain and improve density, thermal fatigue, and resistance to creep and wear. Due to the fact that Nano alumina involves tiny particles, it is highly efficient in the emission of infrared ray. This spherical and white material is powdery and hydrophilic, with a purity of 99 percent, and a particle size of 80 nanometers. The Nano aluminum oxide used in this research is provided by Iran's Pishgaman-e Nano Mavad Company.

Laboratory Plan and Producing the Samples

First, in order to prepare the samples, they were weighed and prepared according to the grading of the soil, and volume of the molds (cylinders with an internal diameter of 9.6 centimeters, and a height of 20 centimeters), and also considering the fact that the grains' relative density is 30 percent. In order to homogenize the mixture before pouring it into the molds, it is mixed in the rotary drum for 5 minutes. Then, the samples were produced based on the laboratory plan, the values determined for nanomaterials and the cement, and also water to cement ratio (1, 1/4, 1/8). Furthermore, 5 percent of silica fume was used in all of the samples, except for the witness sample. For Nano silica and Nano alumina, 0.3, 0.6, and 0.9 percent of the dry cement weight in the injection slurry was taken into account. To achieve a homogeneous mixture in the slurry, first, the nanoparticles were mixed with water for 5 minutes, and then the cement was added. Next, the combination was mixed for 10 minutes at a speed of 5000 rounds per minute. Finally, the mixture was poured into the injection container and injected by a compressor with a 2 bar pressure (figure 2). After 24 hours, the samples were taken out of the molds, and were examined according to ASTMD2166-87 standard after 7, and 28 days of curing (Roshandel, 2009; P.M. Gallagher et al., 2007; C. Butron, 2009; D.F. Lin et al., 2006; Guoping Zhang, 2007; ASTM, 2006). As it was seen after taking the samples out of the molds, some of the samples were imperfectly injected. Therefore, they were reinjected by preparing the repetitive samples, and were finally examined after curing.

Fig. 2. Injection procedure and producing the samples

Results of the Experiments

After curing the samples, they were examined regarding their compressive strength. The results obtained from the different modes regarding water to cement ratio are indicated in what follows. The results of the 7-day and 28-day examination of compressive strength are shown in figure 3. Compressive strength of the samples containing 5 percent of silica fume led to an increase in the compressive strength in both 7-day and 28-day samples. Increasing the amount of Nano silica led to an increase in the compressive strength of the 28-day sample, while this property decreased in the 7-day sample. Furthermore, 0.6 percent of aluminum Nano oxide led to the highest increase in strength for both 7-day and 28-day samples.

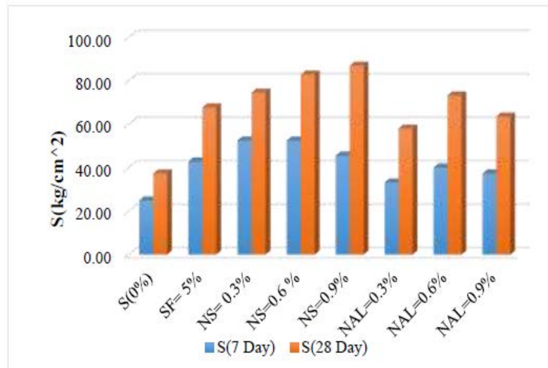

Fig. 3. 7-day and 28-day compressive strength of the samples (water to cement: 1)

The positive effect of 5 percent of silica fume on the samples with 1/4 water to cement ratio can be seen in figure 4. The increasing trend of the samples containing Nano silica is stopped with increasing it at a value of 0.9 percent. Therefore, the optimal Nano silica value for samples with water to cement ratio of 1/4 is 0.6 percent. Studying the effect of Nano aluminum, it can be seen that the compressive strength of the samples is increased compared with the witness sample S (0%). However, increasing the amount of Nano aluminum does not significantly increase the strength.

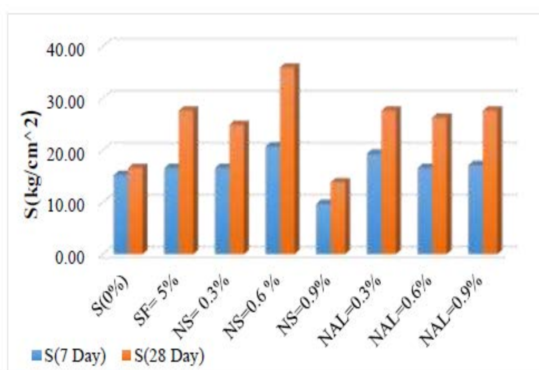

Fig. 4. 7-day and 28-day compressive strength of the samples (water to cement:1/4)

Regarding figure 5, it can be seen that the strength of the 7-day and 28-day samples is increased with increasing the amount of Nano silica. However, this trend is decreasing in samples containing Nano aluminum. Generally, except for the samples containing 0.9 percent of Nano silica, the samples' strength is not significantly increased or decreased compared with the witness sample.

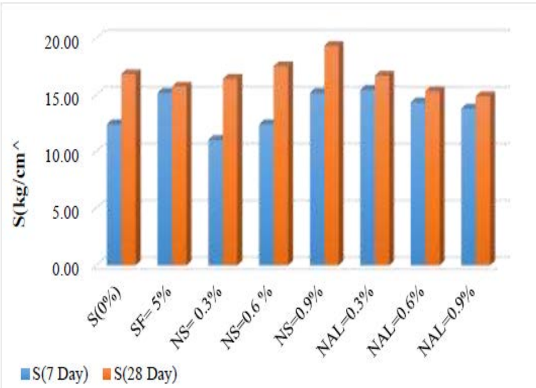

Fig. 5. 7-day and 28-day compressive strength of the samples (water to cement:1/8)

Regarding the figures 6 and 7, it can be seen that 7-day and 28-day compressive strength of the samples with water to cement ratio of 1 is more significant compared with other samples. This, in turn is an indicator of the effect of water to cement ratio on the samples' strength. Furthermore, it can be said that 0.9 percent of Nano silica is not significantly effective on increasing the compressive strength of the samples with water to cement ratio of more than 1. In general, it can be seen that the effect of water to cement ratio is significantly more than Nano silica, Nano aluminum, and silica fume.

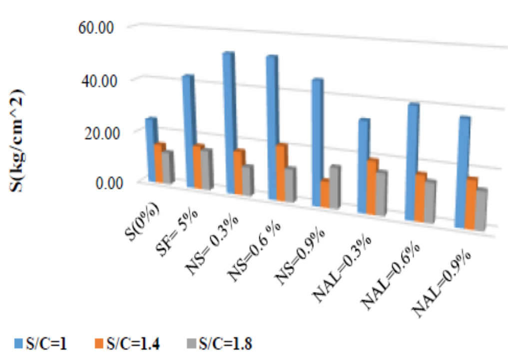

Fig. 6. 7-day compressive strength of the samples with various water to cement ratios

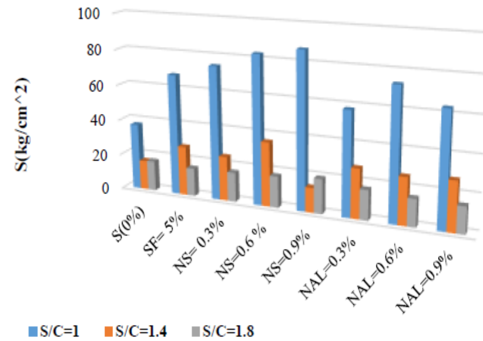

Fig. 7. 28-day compressive strength of the samples with various water to cement ratios

Conclusion

Several experiments were performed for studying compressive strength, with various amounts of nanoparticles and various water to cement ratios. The results are as follows:

1. 7-day and 28-day compressive strength of the samples with a water to cement ratio of 1 is more significant compared with other samples. This is an indicator of the effect of water to cement ratio on the samples' strength.
2. the effect of water to cement ratio on the samples' compressive strength is significantly more than Nano silica, Nano aluminum, and silica fume.
3. With an exception in the 28-day samples containing 5 percent of silica fume (water to cement ratio: 1/8), the positive effect of silica fume on compressive strength could be seen in all of the samples.
4. Increasing the amount of Nano alumina is not significantly effective on increasing compressive strength.
5. Increasing the amount of Nano silica leads to an increase in the compressive strength of the 28-day samples, except for samples with a water to cement ratio of 1/4.

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