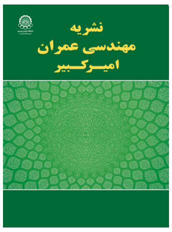

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Evaluation of the Effect of Nano $CaCO_3$ on the Compressive Strength of Sandy Clay Soil with Different Percentage of Clay

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ABSTRACT: Nanoparticles and nano-reinforcement are extensively used in geotechnical engineering and there are various reports on the effect of nanomaterials on the improvement of the engineering properties of various soil types. The effect of nano calcium carbonate (nano CaCO3) on the geotechnical properties of sandy clay (SC) soil containing different levels of clay was investigated. To this end, three types of SC soil containing 10, 20, and 30% clay and 0.3, 0.7, 1.1, and 1.5% nanoparticles were cured for 7, 14, and 28 days and then placed under uniaxial compression test. Also, the experimental results were numerically analyzed by group method of data handling (GMDH) using an artificial neural network. The samples were analyzed using X-ray diffraction (XRD) and scanning electron microscopy (SEM) tests. According to the results, adding nano CaCO3 to SC soils, caused an increase in the uniaxial compressive strength and secant modulus. Moreover, the compressive strength obviously increased over time. An optimum nanoparticle level of 0.7% was obtained for the soils containing 20% and 10% clay. The corresponding nano CaCO3 level for the soil containing 30% clay was 1.1%. The effect of nano CaCO3 as an effective additive on the ultimate compressive strength of the soil was investigated by XRD and SEM evaluations. The results indicated an increase in the crystallinity of particles after adding CaCO3 nanoparticles. Finally, based on numerical analysis of the experimental result, a correlation was obtained to predict the uniaxial compressive strength of the improved SC soil with a mean error of 4%.

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1. INTRODUCTION

In addition to traditional additives, the approach of using additives in nano-size has been recently considered. More atoms appear on the surface by decreasing particle size leading to the dominance of surface properties (such as physical, chemical, electrical, and reactivity properties) and reduced importance of mass properties. Larger surface-to-volume ratios (i.e. specific surface area) are obtained in nanoscale leading to a higher cation exchange capacity. Examples of studies on the application of nanomaterials in geotechnical engineering, especially in the improvement of problematic soils, are reviewed below. Gallagehr and Finstere (2004); Burton *et al.* (2009) and Changizi and Haddad (2015) studied the effect of silica nanoparticles on clay soil properties and reported that the addition of small amounts of nano-silica increased the cohesion of clay [1-3]. Yao *et al.* (2019) studied the effect of magnesium oxide nanoparticles on cement-stabilized soft soil. They found the significant role of MgO nanoparticles on the strength properties of cement-stabilized soft clay [4]. According to nano-geotechnical engineering literature, experimental studies have focused on some nanomaterials (including nano-silica, nano-clay, and nano iron oxide) but few studies were found on nano calcium carbonate ($CaCO_3$) as a secondary stabilizer from a geotechnical point of view. Due to widespread geological dispersion of calcium carbonate and application of calcium carbonate in soil improvement methods such as injection and deep mixing, it is necessary to investigate the effect of nano $CaCO_3$ on soil properties. Accordingly, this experimental study investigated the effect of $CaCO_3$ nanoparticles on sandy clay soils. Also, using the artificial neural network method with the group method of data handling (GMDH) method, a correlation is presented for predicting the uniaxial strength of SC soils stabilized with nano $CaCO_3$.

2. METHODOLOGY

The effect of nano $CaCO_3$ on the uniaxial compressive strength of sandy clay soil was studied experimentally. To this end, sandy clay was prepared from the Caspian Sea coast in northern Iran and clay soil (kaolinite) was purchased from Iran China Clay Industries. The sandy soils used in this study was SP class with the average particle size (D50) of sandy soil equals 0.21 mm. the clay soil used in this study is placed in the CL-class and According to the results of chemical analysis, the main elements in the soil include Si, O, and Al. To study the effect of calcium carbonate nanoparticles on sandy clay soil, SC1, SC2, and SC3 soils respectively with 10, 20, and 30% clay were used. The physical characteristics

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Table 1. Physical properties of soils used in this study

Soil properties	Description	SC1	SC2	SC3
FC (%)	Fine Percent	10	20	30
G_s (kg/m^3)×10^3	Specific Gravity	2.66	2.64	2.62
γ_d (kg/m^3)×10^3	Maximum Dry Density	2.04	2.01	1.99
LL (%)	Liquid Limit	18	19	22
PL (%)	Plastic Limit	14	14	16
PI (%)	Plasticity Index	4	5	6
OWC (%)	Optimum water content	12	14	17

of these three soil types are summarized in Table 1. According to previous studies and considering that the nano $CaCO_3$ used in this study will probably react with the clay part of the soil, different percentages of clay were used to investigate the reactivity of this soil and nano $CaCO_3$.

For samples preparation (specimens SC1, SC2, and SC3 in Table 2), after preparing a homogenous mixture of the soils with certain levels of nano $CaCO_3$ (0.3, 0.7, 1.1, and 1.5%), the mixture was compacted in five layers in a cylindrical mold. A total of 72 specimens were prepared to evaluate the effect of nano $CaCO_3$ on the strength properties of the soil. Then, a uniaxial compressive strength test was performed on these samples and samples without additives in three processing times of 7, 14, and 28 days according to ASTM C617 standard. Also, using the results of experiments on sandy clay (SC) soil specimens, a correlation was proposed for predicting the uniaxial strength of soils based on the GMDH method. The data used in this study include nanoparticle level (*N*), sand level (*S*), clay level (*C*), and curing duration (*t*). These data are used as inputs to the neural network model. The objective function of the neural network model is the uniaxial compressive strength of the soil which is determined experimentally. Using experimental results and taking into account research variables, a correlation is presented for predicting the uniaxial compressive strength of SC soils stabilized with nano $CaCO_3$.

3. RESULTS AND DISCUSSION

To evaluate the effect of nano $CaCO_3$ on the strength of fine-grained cohesive SC soils, the results of the uniaxial compressive strength tests are analyzed. For example, Fig. 1 shows the ultimate strength of stabilized soils with different nanoparticle contents at a curing time of 28 days.

According to the results. Unlike SC1 and SC2 stabilized the strength of SC3 increases as nanoparticle level increases from 0.7 to 1.1%. Scrutiny on stress-strain diagrams for all three specimens showed that the uniaxial compressive strength increases at all curing durations indicating the occurrence of chemical reactions between soils and nano $CaCO_3$. The strain also increases with increasing clay levels. Moreover, the stress-strain behavior of soil specimens becomes more linear with increasing nano $CaCO_3$ levels

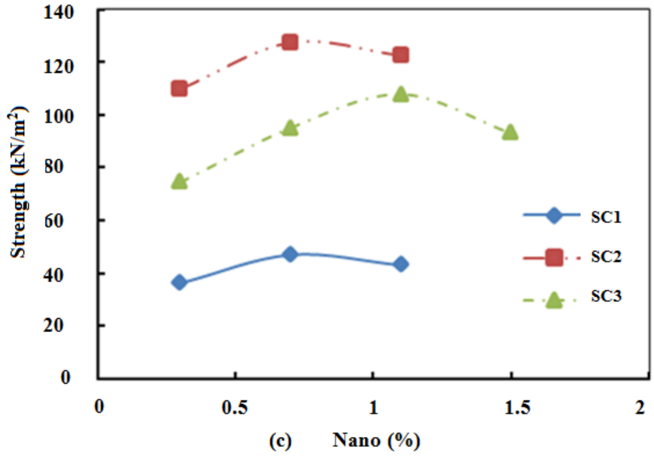

Fig. 1. Ultimate strength of stabilized soils with different nanoparticle contents at curing times of 28 days

leading to an increase in the modulus of elasticity. Also, X-ray diffraction (XRD) analysis was used to determine the phase structure and degree of crystallinity of the soil specimens' stabilized and non-stabilized with nano $CaCO_3$. The result showed the products of calcium silicate hydrate (CSH) reaction and quartz and kaolin byproducts. The intensity of peaks indicates the high degree of crystallinity of the specimens containing nanoparticles. In the numerical part of study 33 experimental data were used to predict the uniaxial compressive strength of the soil by the GMDH method. The input data were divided into training and test data. Of 33 experimental data obtained in the previous stage, 26 specimens were used for designing GMDH structure and the remaining 7 specimens were used for evaluating the performance of the network in predicting uniaxial compressive strength. The GMDH method with 2 hidden layers was considered to obtain a polynomial for predicting the uniaxial compressive strength of the soil where N, S, C, and t respectively represent nanoparticle level, sand level, clay level, and curing duration.

To evaluate the presented artificial neural network, the statistical index of relative error percentage has been used and considering that the relative error rate obtained from the GMDH algorithm is 4.5%, the results indicate the high efficiency and accuracy of this method.

4. CONCLUSION

In this paper, the effect of nano $CaCO_3$ on the strength properties of three soils with different sand and clay levels was evaluated by a uniaxial compressive test. According to the results, adding nano $CaCO_3$ to all specimens caused an increase in the ultimate strength of soil specimens. An optimal additive level of 0.7% for SC1 and SC2 and 0.9% for SC3 was obtained. The ultimate strength of all specimens increased with increasing age. The specimen SC1 showed the lowest strain at failure (brittle behavior) due to its granular nature. The strain at failure decreased by adding nano $CaCO_3$ to the soil. The strain at failure of specimens increased with increasing the clay level. The soil specimen SC2 showed higher strength than the other two specimens given the clay level in the sandy soil. This can be related to the clay level and maximum filling of voids between sand grains. In other words, clay soil has the highest contribution in filling voids between sand grains without displacing grains and with the lowest negative impact on intra-grain friction of the soil. The microstructure analysis by X-ray diffraction shows a high degree of crystallization and formation of the CSH crystalline phase at 25.3 ° and 26.9 °. Experimental results were numerically analyzed by the GMDH method to predict uniaxial compressive strength. The results indicated a mean error of 4.5% representing high consistency of estimation function and experimental results.

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