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Stabilization of sandy soil with geopolymers based on nanomaterials and Taftan pozzolan

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ABSTRACT: In this study, geopolymers based on Taftan natural pozzolan and nanomaterials (nanoclay and nanosilica) were used to stabilize sandy soil. Various parameters such as type of nanomaterial, amount of nanomaterial, alkaline activator solution ratio and curing time were taken into account as the affecting factors on the behavior of stabilized specimens. The unconfined compressive strength (UCS) tests were performed to evaluate the effect of geopolymer and nanomaterials on sandy soil stabilization. Then, the X-ray diffraction and scanning electron microscopy were performed to verify the microstructure of the stabilized soil. The results showed that the addition of pozzolan and nanomaterials to soil and increasing the amount of alkaline solution caused an increase in the compressive strength of the soil. Additionally, the strength of geopolymer specimens increased with the addition of nanomaterials up to 2%, and subsequently due to the accumulation of nanomaterials decreased. The microstructural analysis indicates a strong reaction of chemical additives and the formation of aluminosilicate gel in geopolymer compounds, which itself increases the load-bearing capacity of the soil and stabilized. Based on this study, natural Taftan pozzolan and nanomaterials are appropriate and beneficial alternative materials in the stabilization of earth structures.

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1. INTRODUCTION

Many construction sites have soft and quite compressible soils, whose resistance to applied loads during construction or throughout their useful lifetime is not sufficient and experience failure or excessive settlement [1,2]. The durability and natural resistance of soil can be improved through the process of soil stabilization [3]. One of the most common methods for stabilizing and improving the mechanical properties of soils is the use of chemical stabilizers such as Portland cement. Today, Portland cement produces approximately 5-8 % of the carbon dioxide gas in the world. Approximately, 121 liters of fossil fuels and 111 kilowatt-hours of electricity are consumed per ton of cement on average. [4-6]. Additionally, a large percentage of the raw materials in cement manufacturing comes from the extraction of natural resources which has an adverse effect on the environment and increases the cost, time and energy consumption [5,6]. Hence, researchers are always searching for environmentally friendly replacements for cement.

Geopolymers have been considered to be a proper substitute for cement [7]. Geopolymers were initially developed by mixing geopolymer precursors with an alkaline activator. Geopolymer precursors include a wide range of low-cost aluminosilicate materials, even including such industrial waste as fly ash (class C and class F) and natural pozzolans. Alkaline activators include alkaline solutions of sodium silicate, potassium silicate, calcium carbide and sodium hydroxide [8]. The use of industrial waste as a progression for geopolymers has been evaluated by several geotechnical researchers [9]. Additionally, according to the McLellan report, the cost of geopolymers could be less than that of cement [10].

Furthermore, nanomaterials have been increasingly used in geopolymers with the development of nanotechnology. However, the research on the effects of nanomaterials is scarce on the properties of geopolymer in soil stabilization. In this study, Taftan pozzolan as an eco-friendly material and nanomaterial were used to stabilize weak soils. For this purpose, factors affecting the compressive strength of the stabilized soil were experimented and evaluated, which included the curing time, the amount of alkaline solution and application and amount of nanomaterials. Alkaline solution with two different ratios of 0.3 and 0.45 to the total pozzolan weight and nanomaterial (nanosilica or nanoclay) content of 1, 2, 3% of the total soil weight were examined to determine the optimum mix design. Scanning electron microscope (SEM) and X-ray Powder Diffraction (XRD) microstructure analyses were used to evaluate and interpret the results of the stabilized specimens.

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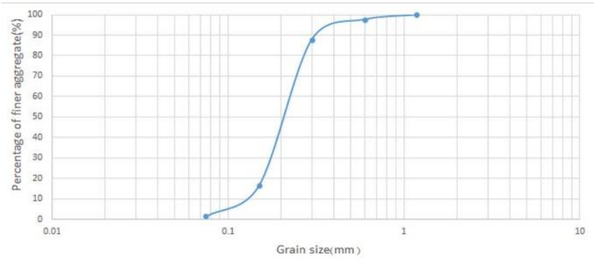

Fig.. 1. The particle size distribution of the investigated soil.

Table 1.Chemical properties of Taftan pozzolan, nanoclay and nanosilica

Chemical Composition (%)	Taftan Pozzolan	Nanoclay	Nanosilica
SiO_2	60.90	50.95	>99%
Al_2O_3	18.45	19.6	-
SiO_2+Al_2O_3	84.45	70.55	>99%

2-MATERIALS

2-1- Soil

Considering the particle size distribution (PSD), as shown in Figure 1, the soil is classified as poorly graded sand (SP). The optimum moisture content was determined 13 % after standard compaction test.

2-2- Natural Taftan pozzolan

Natural Taftan pozzolan collected from Taftan volcano district in Sistan and Baluchestan province, Iran as illustrated in Table 1.

2-3- Nanomaterials and Alkaline Activator

The nanomaterials used in this investigation has been nanoclay and nanosilica as presented in Table 1. The alkaline solution used in this study is a sodium hydroxide solution (NaOH).

3-METHODOLOGY

The water and the sodium hydroxide solution were weighed and the soil and pozzolan were then dry-mixed by hand until uniformity was reached. The amount of water in the sodium hydroxide solution was determined for each mixture. Then, the amount of water required to reach the optimum moisture for the soil was determined. A part of this water was used for making the alkaline solution, and the other part (extra water) was added to the homogeneous soil and pozzolan composition. The sodium hydroxide solution and nanomaterials were mixed slowly for eight minutes to obtain a homogeneous solution. Then, the solution was added to the initial mixture (homogeneous soil and pozzolan mixture) and mixed. The resulting mixture was poured into three layers of a mold, with each layer compacted four times with a standard

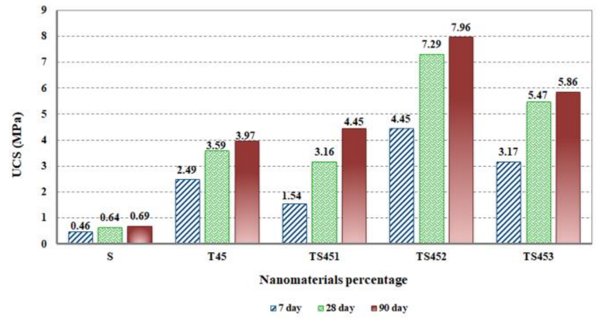

Fig. 2. Comparison of the effect of a different nanosilica percent on UCS of Taftan pozzolan with an alkaline solution ratio of 0.45.

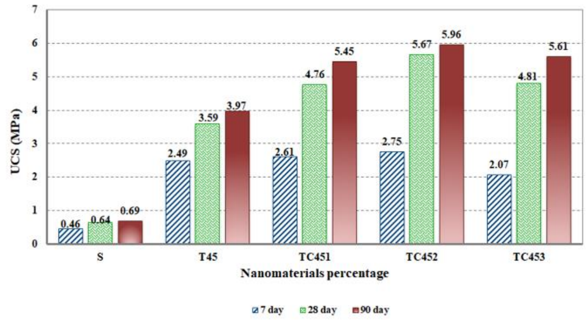

Fig. 3. Comparison of the effect of different nanoclay percent on UCS of Taftan pozzolan with an alkaline solution ratio of 0.45.

hammer, having a weight of 4 kg and a height of 30 cm.

The specimens were removed from the mold and treated in room temperature until they reached their desired treatment period (7, 28 and 90 days). Three specimens were made from each stabilized soil specimen. The specimens are classified into three general groups of Taftan pozzolan, soil and cement. They are divided group 1 (specimens containing Taftan pozzolan with an alkaline solution and pozzolan percentages of either 0.3 or 0.45, 1-3% of nanosilica or nanoclay, and specimens without nanomaterials (pozzolan only)), group 2 (pure soil) and group 3 (stabilized with cement percentage of 7% and 15% of soil weight).

4- RESULTS AND DISCUSSION

4-1- Mechanical properties

The compressive strength of specimens for different curing time is obtained as shown in Figures 2 and 3 for some groups 1 specimens. The compressive strength was increased for all specimens by an increase in curing time. However, the rate of increase was not constant over time and was more significant during the first 28 days. After 90-days treating, for different nanomaterial percentages and in cases of NaOH solution ratio of 0.3 or 0.45, the optimum percentage of nanomaterial was 2%

After 90-days treating, for different nanomaterial percentages and in cases of NaOH solution ratio of 0.3 or 0.45, the optimum percentage of nanomaterial was 2%. The 90-day compressive strength of specimens stabilized with nanosilica higher than nanoclay specimens. According to the chemical properties of materials as stipulated in Table 1, nanosilica contains 99% silica, while nanoclay only contains 50.95% silica. Since silica is the main cause of strength in geopolymer products, the high strength of specimens with nanosilica can be justified [11]. The compressive strength of specimens with 0.3 alkaline solution was 10-20 % lower than that of the specimens with 0.45 alkaline solution. Comparison of cementitious and geopolymer specimens shows that the addition of nanomaterials, especially nanosilica to geopolymer specimens shows a significant increase in strength compared with cement stabilized specimens.

4-2-Microstructural analysis (XRD and SEM)

The XRD analysis showed that the severity of peaks in stabilized specimens with pozzolan and nanosilica (the optimum percentage) was decreased compared to pozzolan and pure soil specimens. The SEM analysis showed that the soil stabilized with pozzolan and nanosilica (the optimum percentage) had a more homogeneous structure, less porosity and more uniform surface than the other specimens confirming the obtained optimum mixture.

5- CONCLUSION

Natural pozzolans and nanomaterials are effective stabilizers for sandy soils with a brilliant increase in the compressive strength. For appropriate geo-polymerization and enhanced the mechanical behavior of stabilized soils the optimum amount of nanomaterial (in this study 2%) was necessary. The microstructural analyses (XRD and SEM) confirmed the formation of geopolymer and effectiveness of using pozzolan and nanomaterial to stabilizing soils.

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