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Enhancement consistency and compaction characteristics of clayey soil using nano silica material

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ABSTRACT

The use of stabilizing technologies has significantly expanded in recent years specially when sites are frequently construction in poor land locations. This study suggests using nano-silica to improve clayey soil's functionality. A range of nano-silica concentrations (0, 0.1, 0.2, 0.4, and 0.8) were used. Laboratory testing was used to identify Atterber's limitations, the optimum moisture content (OMC), the maximum dry density (MDD), and microstructural examination. According to the study, treating soil with 0.4-0.6% nano-silica yields the best results. According to the result, the liquid limit (LL) and plastic limit (PL) are reached maximum at 0.6% nano-silica, while the plasticity index is at its lowest point. The results showed that incorporating nano-silica into clay samples will lower the maximum.

Keywords: Nano materials; consistency; clay; stabilization.

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1. Introduction

Enhancing the soil's permeability, flexibility, and durability as well as its mechanical properties, bearing capacity, and stability are the principal purposes of soil stabilization. Three techniques of soil stabilization can be used: physical, chemical, and mechanical methods. The soil is chemically stabilized by adding additives to enhance its properties [1]. Cement or lime chemical stabilization is a tried-and-true method for enhancing soil performance [2], [3]. However, over the past 20 years, nanotechnology has developed into a highly popular interdisciplinary field. It is important to enhance soil by employing nanomaterials as a way to improve soil's geotechnical qualities. To understand the impact of nanomaterials on soil geotechnical qualities, numerous experiments employing various soil tests have been conducted. Most of the recent ten years' worth of research was reviewed by [4]. As a result, many researchers investigated how introducing nanomaterials affected the characteristics of soil. All findings indicated that adding nanomaterial to soil improves its physical and mechanical qualities. However, the degree of improvement depends on not only the parameters of the soil but also on the type and quality of nanomaterial. Nano-silica has been widely considered in pavement to enhance the rheological properties of asphalt pavement and, ageing qualities [5]. Researchers discovered that the clay's swelling index decreases when nano-silica is added [6]. They found also that adding more nano-clay leads to increase in liquid, plastic limits (PL) and Shear Strength (SS) parameters [7]. Compressive Strength (CS) of earth bricks-nano-clay is also improved by using nano-clay to become about five times that of regular earth bricks and can get the properties of sustainable materials [8]. According to much research on the usage of nano-SiO_2 by [9], there is an observed improvement in the UCS of the soil which is more significant than those obtained when using lime or cement. To comprehend their impact on compaction qualities, [10] study the effect of using two different forms of nanocarbons, carbon nanofiber and multiwall carbon nanotube. This is due to the reduction of OMC resulted from filling the voids in the soil with nanocarbons. They noticed a correlation between the percentage of nanomaterials used and an increase in the (OMC). Additionally, nanomaterials have denser particles than normal soil, increasing the (MDD) of treated soil. "Ref., [11]" looked at the impact of silty clay-nano kaolinite percentages. The increase in the nano kaolinite content in the silty loess soil was shown by the results of the Atterberg limit tests to have increased the LL and PL. The plasticity index (PI), however, stayed constant at the time at the lower percentage and dropped even more after the addition of 5% nano kaolinite. "Ref., [12]" The physical properties and bearing capacity of expansive soil can be improved also by using commercial nanoparticles depend on a silicates liquid. The life cycle assessment demonstrated that the use of nanoparticles lessens the negative environmental consequences and the control section by 30 cm.

"Ref., [13]" employed nano-carbon to remediate gypsum soil that was taken from the Iraqi city of Al-Najaf. The findings demonstrated that adding nano-carbon has an impact on collapse potential, while soil cohesiveness is partially diminished when nano-carbon is applied at a 0.8% concentration. However, the friction angle increased by around 19%. The ideal percentage for employing nano-carbon is between 0.8 and 1.2%. When High Reactivity Attapulgite (HRA) was considered by [14], a reduction of 13-90% in the collapse potential and a raise of 183 kPa in the unconfined compressive strength (UCS) were observed. In this study, enhancement of physical and microstructural characterization of clayey soil is evaluated using nano silica as pozzolanic additives.

2. Soil and nano silica

The used natural soil was taken from 50 to 100 cm depth below the natural ground surface in Baghdad city, Iraq. The soil sample was processed through removing rubbish, air drying, crushing, and properly blending. Then it was kept in double nylon bags. Physical, chemical, and classification tests were carried out according to [15]. Wet sieving was performed and the grain size distributions are shown in Figure 1. The soil is classified as silty clay by ASTM and has the designation (CL) in the Unified Soil Classification System (USCS). It also contains 58% clay, 39% silt, and 3% sand. The physical characteristics including the specific gravity (Gs), LL, PL, and PI are listed in Table 1.The common used nanomaterial is Nano-silica. Additionally, nano-silica can be extensively used in a variety of industries, including glass, steel, fiber, batteries, paints, adhesives, cosmetics, ceramics (sugar), porcelain, gypsum, and many others. Numerous products, including paint, plastic, colored rubber, magnetic materials, and pigments, utilize nanoparticles. Nano-silica improve the stiffness and strength of the soil because of its filling-void effect, strong pozzolanic activity, small size, and high specific surface area (SSA) [20]. Table 2 summarizes a few of the physical and chemical characteristics of nano silica. It was determined that the mixtures should contain 0.1, 0.2, 0.4%, and 0.8% of nano silica.

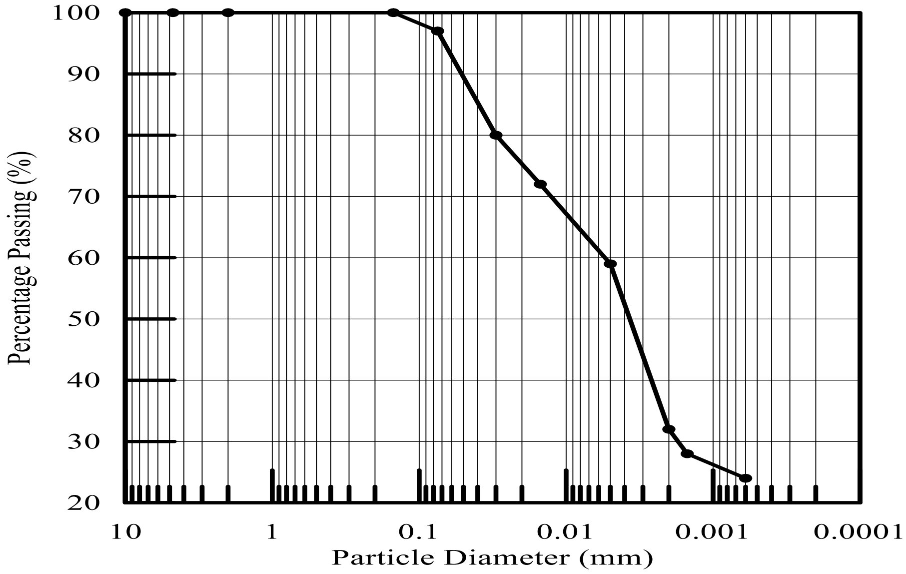

Figure 1. Particle size distribution of the soil

Table 1. Physical properties of the soil

Soil properties	Value	Test Method
Specific gravity, Gs	2.71	[16]
liquid limit, LL (%)	38	
Plastic limit, PL (%)	23	[17]
Plasticity index, PI (%)	15	
MDD (Maximum dry density), g/cm^3	1.6	
OMC (Optimum moisture content), %	21	[18]
% fines (Passing sieve No. 200, (%)	97	
Classification of soil according to the USCS	CL	[19]

Table 2. Physical and chemical properties of nano silica

Property	Value
Purity %	99
Size (nm)	15-50
Specific Gravity	2.2-2.4
Specific Surface Area (m^2/g)	180-700
pH	4-7
Form	Powder
color	white

3. Sample preparation

First, a mechanical mixer was used to mix the soil with varying concentrations of nano silica in a container for 45 minutes. Then, to create uniform samples, a distilled water with little amount based on the OMC of each mixture was gradually added to the mixture. According to [21] the mixing process was prolonged for another 20 minutes to achieve consistency. In Figure 2, a sample of nano-silica is depicted.

(a) (b)

Figure 2. (a) Nano-silica sample, (b) Nano-silica mixed soil

4. Results and discussion

4.1 Soil plasticity

To determine the PI, LL and PL value tests were carried out accordance to [17] standard. Figure 3 illustrates the reduction in PI soil mixture caused by the increase in the nano-silica content. The addition of 0.1%, 0.2%, 0.4%, and 0.8% nanosilica has a significant impact on increases in the LL and PL of about 11%, 18%, 29%, and 34%, respectively, and decreases in the PI of about 7%, 20%, 27%, and 33%. When the soil contains 0.6% nano-silica or less, the link between the LL and PL limits and the reduction in PI becomes appreciably tighter, and the soil is classified as MH. According to [22] this phenomenon is caused by nano-ability silica's to absorb more water and it is specific surface area and surface charge high.

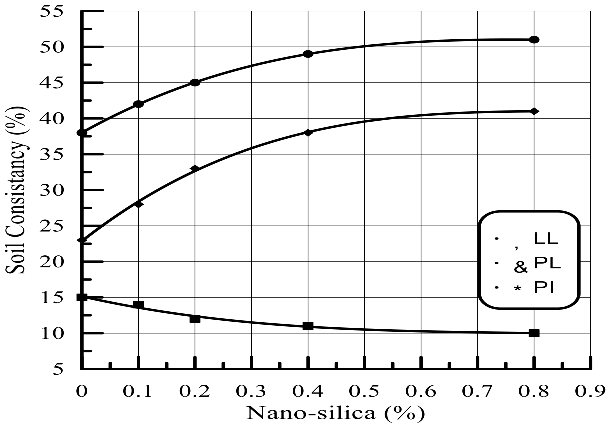

Figure 3. Atterberg's limits of the treated soil with nano-silica

4.2 Compaction test

By using a modified Proctor test in accordance with [18], MDD and the OMC for the soil containing nano-silica were determined and compared to those of natural soil, as shown in Figure 4. According to Figures 5 and 6, decreasing the MDD and raising the OMC were the consequences of the increase in nano-silica in the soil mixture. The findings also indicate that by increasing the nano-silica by more than 0.6%, the lowering and growing rates of the MDD and OMC, respectively, are closer. This might be because nano-silica has a lower density than natural soil. Nano-silica also has a higher activity area and needs more water to hydrate, which raises the OMC. When Nano silica is added, the free silt clay fraction can be reduced resulting in the formation of a coarser material. According to [22], [23] more water is needed to compact the mixes.

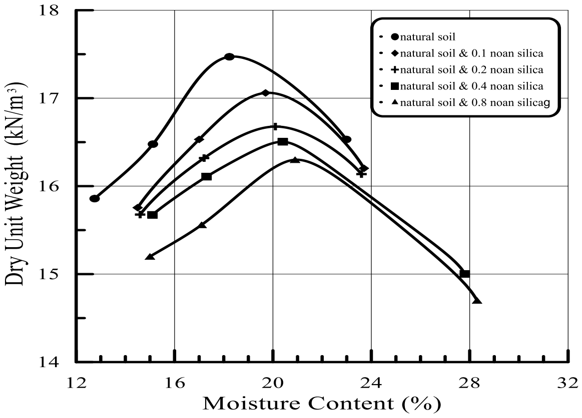

Figure 4. Compaction curve for the natural soil and soil treated with nano-silica

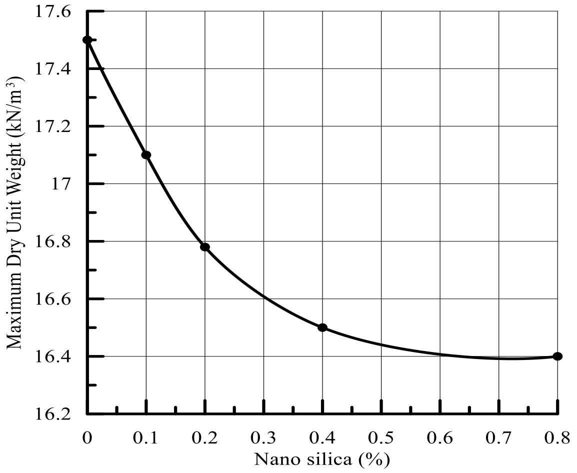

Figure 5. Effect of nano-silica on MDD of soils

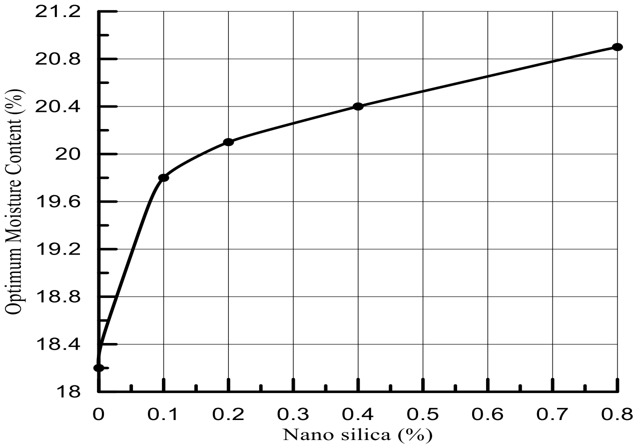

Figure 6. Effect of nano-silica on OMC of soils

4.3 Microstructural scan

Figure 7 displays images taken with (SEM) of treated and untreated soil. It can be seen that soil changes from being scattered to being flocculated, because the soil becomes denser and has fewer voids when mixing with nano silica. In addition, increasing the proportion of nano silica above 0.4% leads to agglomerations because of uneven and flimsy interactions with the soil particles. The micrograph shows the silt-fine, clay-like texture (open fabric) that occurs from flocculated arrangements. Nanomaterial composites were used to cover the clay and silt fragments. The pore spaces in the untreated soil have a microstructure with a rather high porosity system. Adding nano-silica reduces the microstructural holes and alters the clayey soil's condition.

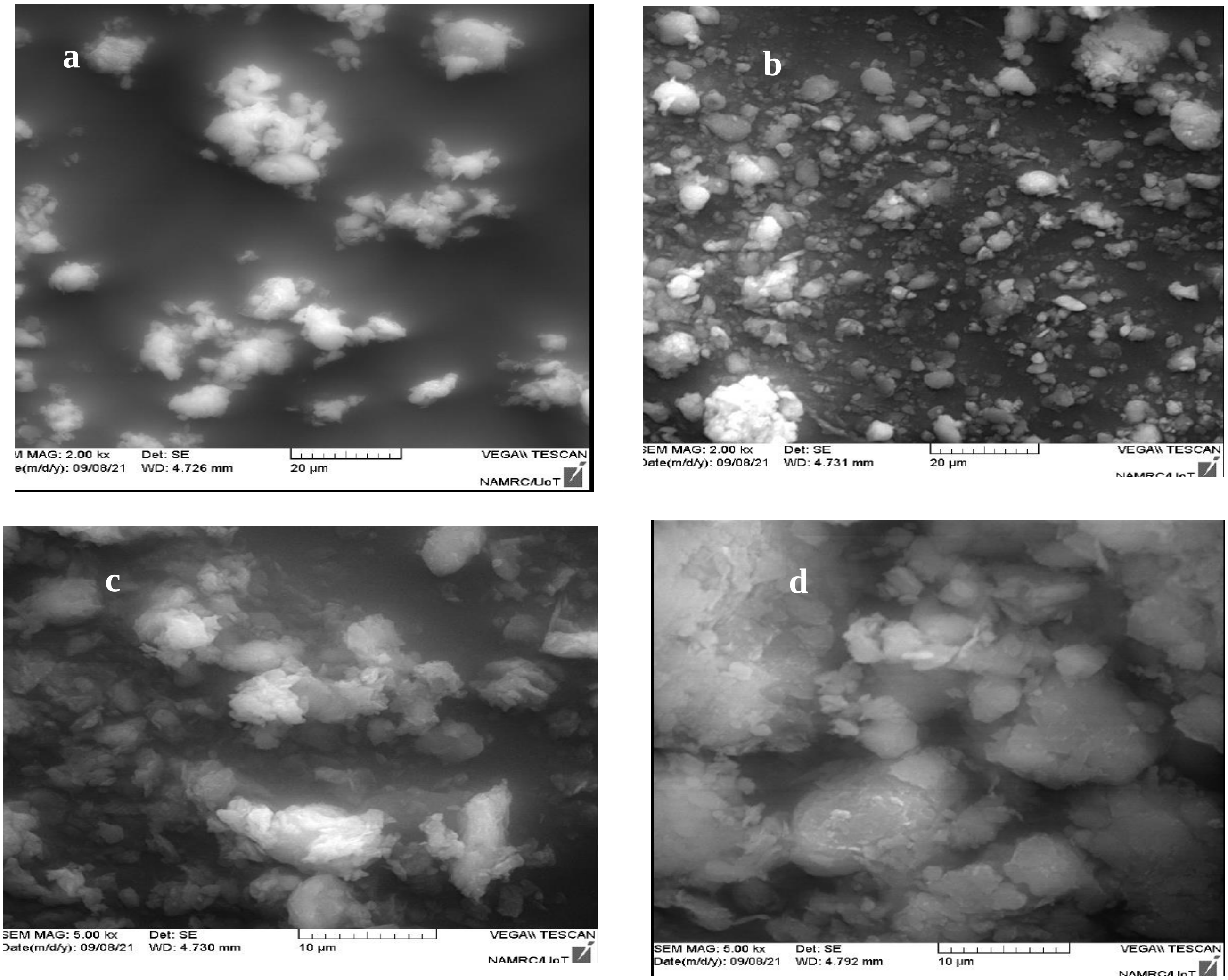

Figure 7. SEM images of (a) natural soil, (b, c and d) soil with nano-silica

5. Conclusions

In this work, the effect of modifying soil with nano-silica on the texture of clayey-soil was developed. The following conclusions are drawn:

1. The PI decreased by about 33% when the content of nano-silica increases from 0% to 0.8%.
2. Atterber's limits increased by about (34% and 78%) for LL and PL respectively. The results indicate that using more 0.6% of nano-silica the lower rate of decreased in the PI and lower increased in LL and PL.
3. The soil classification is change from CL to MH with increasing the nano-silica beyond 0.4%.
4. The MDD of treated soil with nano-silica decreased, while the OMC increased by about 6.3%, 14.8% respectively as nano-silica percent increased from 0% to 0.8%.

5. Using nano-silica reduces the microstructural holes and alters the clayey soil's condition.
6. Finally, the qualities of stabilized soil are improved by the use of nano-silica. By reducing the thickness of the layers due to the improvement in consistency and compaction, it is possible to achieve the same behaviors as in the project solution while using less material.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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Abbreviations and acronyms

CS	compressive strength
NCCS	nano-clay on the compressive strength
UCS	unconfined compressive strength
OMC	optimum moisture content
MDD	maximum dry density
LL	liquid limit
PL	plastic limit
HRA	High Reactivity Attapulgite