The Importance of Transition from Micro to Nano Clay Size in Improving the Engineering Properties of Sandy Soils (Poorly Graded Sand)

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Abstract: Nano-clays are a broad class of naturally occurring inorganic minerals in the form of plate-like alumina-silicate layers with thickness between 1nano-meter to 10micro-meters. Due to the very small sizes of nanoparticle, they provide a large specific surface area which make them to absorb water and fill the voids within the soil particles.

The aim of this paper is to investigate the use of nano-clays for modifying the engineering properties of granular soils. This type of soil covers large parts of the land surface and cause many problems for the development of urban areas, infrastructure projects and instability of slopes along the railways and road networks.

The mineral composition of the granular soil mainly consists of quartz grains and the soil types are classified as poorly- to well-grade materials. In order to evaluate the effect of micro and nano clay on modification of geotechnical properties of the sand, different percentage of 0.5%, 1%, 2% and 4% of micro-clay and percentage 0.5%, 1%, 2%, 4%, 6%, 8%, 10%, 12% and 14% nano-clay. In order to determine the value of its peak were done. Then mixed with the sand and a number of tests such as compaction test, direct shear test are conducted on the samples. The result shows that maximum dry unit weight and maximum optimum moisture content were obtained when 10% nano-clay mixed with the sand. It was also was noted that the increment of nano-clay and micro-clay causes gradual increases and gradual decreases of the shear strength of the sample, respectively.

Keywords: Nano-materials, nano-clay, kaolinite, sandy soils.

1. INTRODUCTION

Ground modification techniques have become a major part of civil engineering practice in recent years, and their use is growing rapidly as infrastructural development demand for land reclamation and utilization of soft or unusable soils. Soils are recognized as most abundant natural resources and are used in constructing many engineering projects such as embankment dams, road basement and retaining walls. They deserve to be treated to gain suitable requirement needed for the proposed projects. The application of nanoparticles for reinforcing the strength of soft soil is regarded as suitable technique of ground modification.

The application of nano-clay in soil treatment has been in the interest of many researchers in recent years. For example, Majeed et al. investigates the stabilization of soft soil with nano-materials [1]. Majeed and Taha, studied the effect of nano-materials treatment on geotechnical properties of soft soil in Penang, Malaysia [2]. Padidar et al. used nano-clay to control the soil erosion in Esfahan, Iran [3]. Neethu and Remya, evaluate the engineering behavior of nano-clay stabilized soil [4]. The influence of nanoclays on compressive strength of earth bricks was investigated by Niroumand et al. [5].

The aim of this paper is to investigate the effect of micro and nano-clay particles on modifying the engineering properties of aeolian sands. This type of sand is most abundant in large part of central desert of Iran and along the coast line in the north and south part of the country where the stability of many constructions could be affected by the presence of this type of soils.

1.1. The Importance of Transition from Micro to Nano

At the micro scale, most of the properties remain generally the same as those for bulk materials. The decrease of one or more geometries dimension down to the nano scale completely modifies the behavior of the material. Transitioning to the nano scale implies an enormous increase of the surface area with respect to the volume. The mean dimension of a grain in polycrystalline materials is generally of the order of several tens of microns. As such, only one in a thousand atoms is located at the boundary. If the size is reduced to 12nm, 15% of the atoms are found at the boundary. For a size of 5nm, 40% of the atoms will be on the interface. Figure **1**, shows the percentage of atoms at the surface of a hexagonal close-packed of full-shell cluster. For a low number of shells, the

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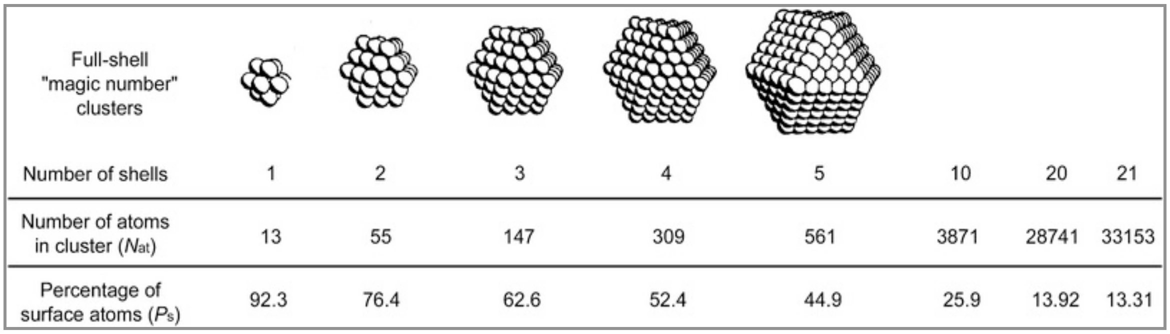


Figure 1: Representation of hexagonal close packed full-shell clusters [6].

number of surface atoms becomes important, and their behaviors are completely different from the inner atoms. This situation accounts for the catalytic properties of nano crystalline particles. The transition from micro to the nano scale has a direct bearing on most physical properties, such as modulus of elasticity, electrical and thermal conductivities, magnetic properties, and catalytic phenomena [6].

2. MATERIAL AND METHODS

2.2. Granular Soil

Aeolian sand is a type of quartzite sand that formed by the action of wind blow in desert and coastal areas. The sand is almost cohesionless, granular in shape and has very loose materials composition. The physical properties of the pure sand used are summarized in Table **1**.

Table 1: Physical Properties of the Aeolian Sand

Physical Parameters	Typical Values
angular coefficient	<1.3
specific gravity (GS)	2.73
colour	white
min. void ration (e_{min})	0.44
max. void ration (e_{max})	0.71
coefficient of uniformity (cu)	2.28
coefficient of curvature (cc)	1.75
water content (WC)	0.032

2.2. Clay material

Clay materials studied in this paper are a type of Kaolinite with mineralogical composition derived from XRD analysis as shown in Table **2**. The liquid limit and plastic index of the clay were 60% and 45% respectively. The particle size distribution curve of the clay is shown on Figure **2**.

Table 2: Mineralogical Composition of Clay Material

Mineral Composition	Percentage
Kaolinite	64 ± 0.2
Quartz	27 ± 2
Calcite	2.1 ± 0.5
Total feldspar	0
Other	6 ± 1

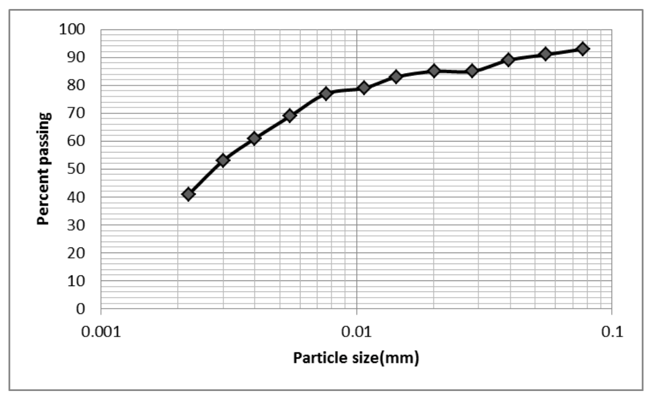


Figure 2: Particle distribution curve of Kaolinite.

2.3. Nano-clay production

In order to produce the nano-clay materials, the clay was pulverized using a planetary ball mill. The performance of the equipment is based on rotation of different sizes of balls at high speed (600 rpm[1]) in steel cup container with two types of transition and circular rotation. The clay specimens were loaded in small amounts in ball mill. The 20 sintered corundum balls used for grinding have the diameter of 5mm. The milling time to prepare each batch was 6 hours and with the speed of 315 rpm while water was added to

[1] Rotation per minute

(**a**) (**b**)

Figure 3 (**a**)**:** A general view of ball-mill equipment. (**b**) An example of FESEM image of kaolinite.

the sample during the operation to decrease the heat. An electronic FESEM microscope is then used for analysis and imaging of particles in their natural state. It also will be useful to measure the size and to scan the morphology of the fine particles. A general feature of ball mill equipment and an example of a FESEM image of nano-clay are shown in Figure **3a** and **3b**, respectively.

2.4. Sample preparation

Three types of soil samples were prepared in this research and the effects of additive material on the natural behavior of the aeolian sand were examined. The samples were prepared in three categories as the following set up:

1. Pure aeolian sand without any additive.
2. Sand mixed with 0.5%, 1%, 2% and 4% of micro-clay.
3. Sand mixed with 0.5%, 1%, and 2% to 14% of nano-clay.

Example features of nano-clay with sand taken by FESEM microscope are presented on Figure **4**. All the samples were undergone two series of tests including standard compaction test and direct shear tests.

3. RESULTS

3.1. Compaction Test Analysis

A series of standard compaction tests in accordance with ASTM D698 were performed on three types of samples, including, pure aeolian sand, mixture of sand with micro-clays (with different percentage) and mixture of sand with nano-clays (with different percentage). The relationship of dry density and moisture content for all samples are plotted on Figure **5a**, **5b** and **5c**. A comparison of the test results is also presented on Figure **6**. The results indicate that the maximum dry density of pure sand is lowest with higher percentage of moisture content. The compatibility of the mixture of sand with micro-clay shows no special trend. On the other, as the percentage of nano-clay increase the maximum dry density of the samples increases very sharply. It can be explained that due to

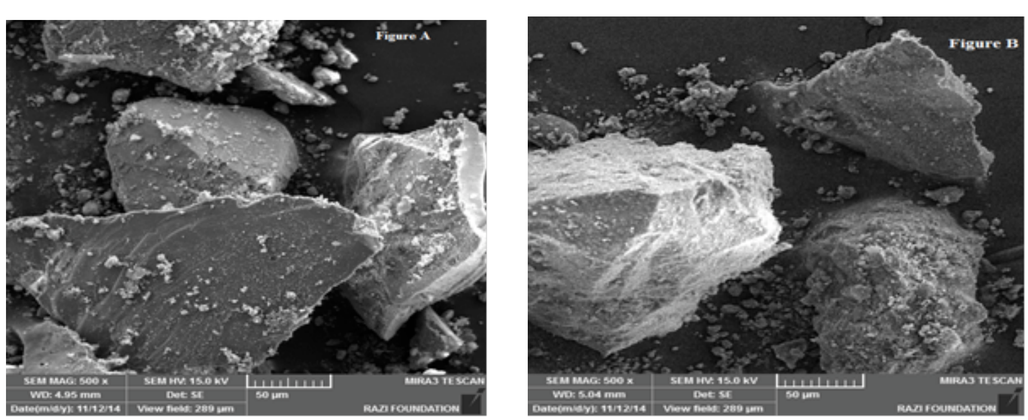
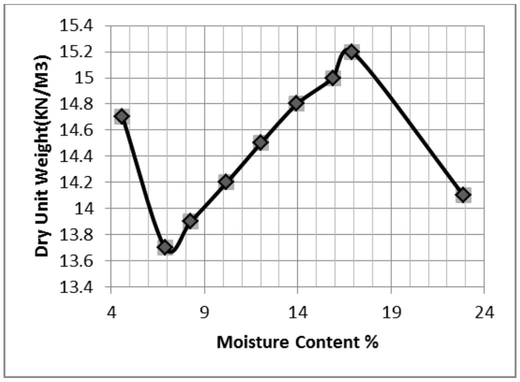
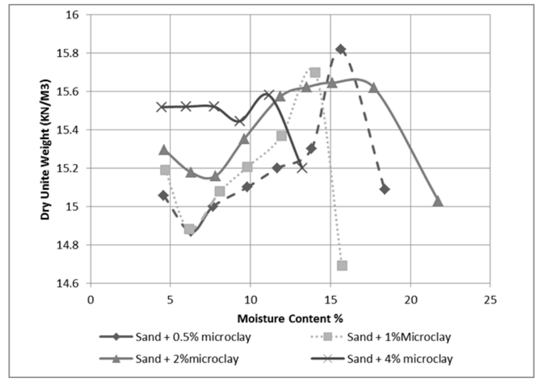


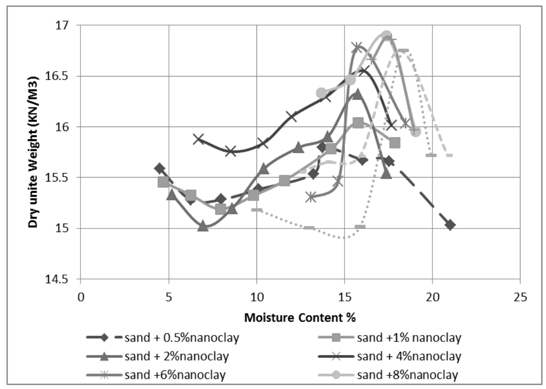
Figure 4: Images of sand mixture with nano-clays under FESEM scale.



(**a**). Pure sand



(**b**). Mixture of sand and micro-clay



(**c**). Mixture of sand and nano-clay

Figure 5: Plots of compaction test results.

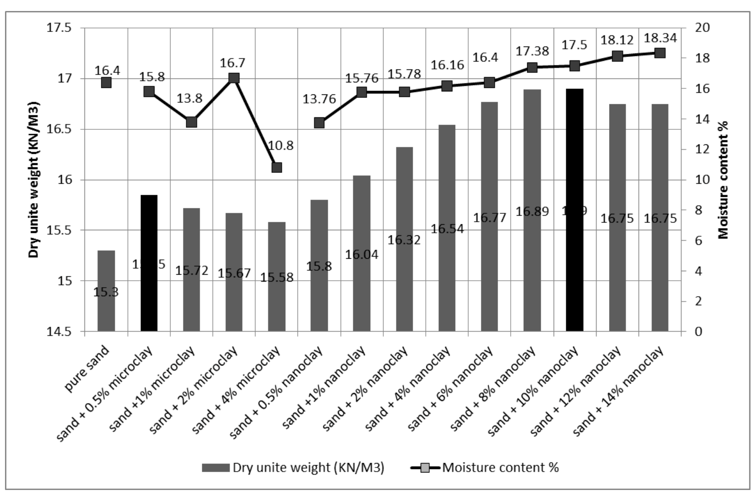


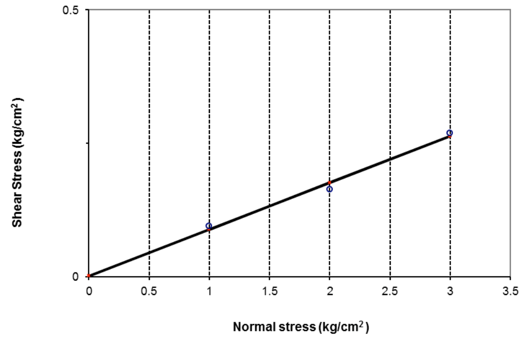
Figure 6: Comparison of compaction test results.

the large specific surface area of nano-clay particle with large specific surface area is suitable for enhancing the strength of pure aeolian sand.

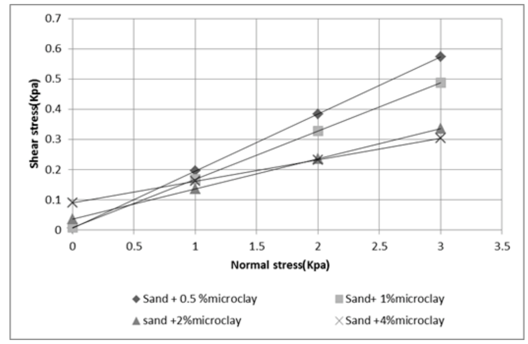
3.2. Direct Shear Test

The shear strength of soil samples were evaluated by conducting the direct shear test (ASTM D3080) on pure sand sample and sand mixed with different percentage of micro and nano clays. The tests were performed on cylinder shape samples with radial and height of 6 and 2cm, respectively. The samples were test under three constant normal stresses of 35, 70 and 105 kN/m^2. Plots of shear strength results for all samples are shown on Figure **7a**, **b** and **c**.

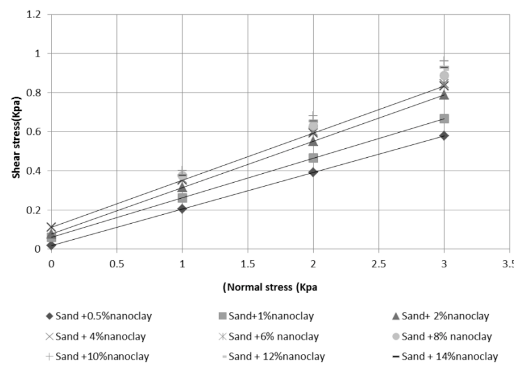
A summary of shear test results are presented in Table **3**. The shear strength of the pure sand recorded



a. Pure sand



b. Mixture of sand and micro-clay



c. Mixture of sand and Nano-clay

Figure 7: Plots of direct shear test results.

Table 3: Summary of Shear Test Results

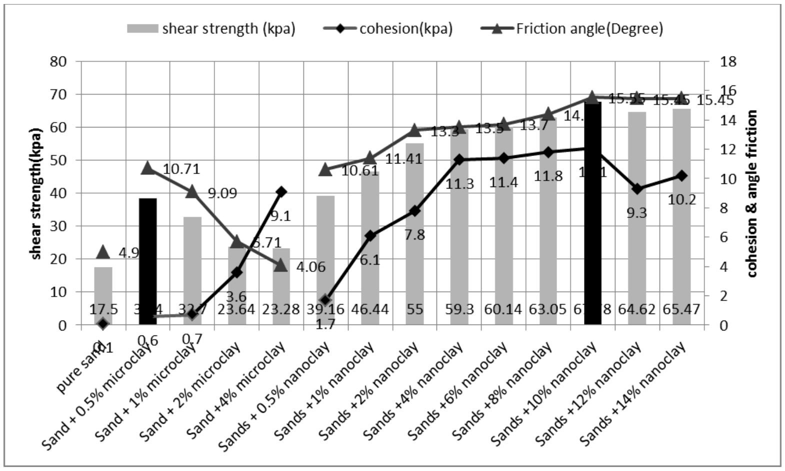
Type of Samples	Shear Strength (kPa)	Cohesion (kPa)	Friction Angel (Ø°)
Pure sand	24.3	0.3	14
0.5% micro-clay	53.0	0.41	28
1% micro-clay	46.9	1.50	25
2% micro-clay	33.0	3.86	17
4% micro-clay	28.0	8.56	11
0.5% nano-clay	29.4	0.33	27
1% nano-clay	39.8	05.8	29
2% nano-clay	47.5	08.9	31
4% nano-clay	54.1	10.2	33
6% nano-clay	60.14	11.4	13.7
8% nano-clay	63.05	11.8	14.38
10% nano-clay	67.78	12.1	15.55
12% nano-clay	64.62	9.3	15.45
14% nano-clay	65.47	10.2	15.45

the lowest value of 24.3 kN/m^2. For sand mixed with micro-clay, the shear strength decreases as the percentage of micro-clay increase, in contrast, the shear strength increases as the percentage of nano-clay increase. A comparison of shear strength values of all samples and their internal friction angle (Ø) and amount of cohesions (c) are demonstrated on Figure **8**.

4. DISCUSSION

The following conclusion can be derived from this paper:

1. A ball mill is a suitable equipment to produce nano-clay for laboratory scale samples.



Shear strength and shear parameters

Figure 8: Comparison of shear strength of samples.

2. The use FESEM microscope to analysis and imaging of particles can be recommended for the procedure of preparing the nano-particles.

3. Additive materials such as micro-clay and nano-clay improve the geotechnical properties of granular soil.

4. The mixture of micro and nano clays with sand shows an increase of compatibility of the pure sand and the best effect is obtained when the sand is mixed with 10% of nano-clays.

5. The gradual increment of micro-clay additive to the pure sand shows a gradual decrease of their shear strength. In contrast, the gradual addition of nano-clay causes a gradual increment of their shear strength parameters.

6. In general the nano-clay admixture with aeolian sand can be considered as a suitable method for improving the engineering properties of soft soils.

REFERENCES

[1] Majeed ZH, Taha MR and Jawad IT. Stabilization of soft soil using nanomaterial's. Res J Appl Sci Eng Technol 2014; 8(4): 503-509.

[2] Majeed ZH and Taha MR. Effect of nanomaterial treatment on geotechnical properties of a Penang soft soil. Journal of Asian Scientific Research 2013; 2(11): 587-592.

[3] Jalalian PM, Abdouss A, Najafi MP, Honarjoo N and Fallahzade J. Effect of nano clay on soil erosion control. Proceeding of NANOCON Conference, Brno, Czech Republic, EU 2014.

[4] Neethu SV and Remya S. Engineering behaviour of Nano clay stabilized soil, proceeding of Indian Geotechnical Conference Boorkee 2013; 1-7.

[5] Niroumand H, Zain MF and Alhosseini SN. The influence of nano-clays on compressive strength of earth bricks as sustainable materials. Procedia-Social and Behavioural Sciences 2013; 89: 862-865. http://dx.doi.org/10.1016/j.sbspro.2013.08.945

[6] Majeed ZH, Taha MR and Jawad IT. A Review of Stabilization of Soils by using Nanomaterial's. Aust J Basic Appl Sci 2013; 7(2): 576-581.

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