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A Review of Stabilization of Soils by using Nanomaterials

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Abstract: Nanotechnology revolves around the creation of a varied collection of nanomaterials (NM), which encompass nanoparticles (NP) along with nano objects. NM are known to be 100 nm lower in terms of dimensions whereas nano objects fall two dimensions lower. An example of this phenomenon can be observed through carbon nanotubes. Nanoparticles are described as materials three dimensions lower than 100 nm. This paper reviews the application of nanotechnology in geotechnical engineering. It discusses soil stabilization and its types, as well as the nanomaterial additives used in soil improvement, and analyzes its effects on soil. Furthermore, this work also discusses the influence of recent advances in nano-instruments and electron microscopes as well as their application in geotechnical studies.

Key words:

INTRODUCTION

The idea of nanotechnology was first introduced in the 1959 by Richard Feynman in his lecture entitled “There’s Plenty of Room at the Bottom” (R. Feynman, 1960). At the time, the term “nanotechnology” had not yet been coined. This technology made a significant and rapid progress years later. Nanotechnological achievements provided a modern approach in geotechnics. Each field of science had a specific definition for nanotechnology, and the National Nanotechnology Initiative (NNI) provided a comprehensive definition of nanotechnology (NSTC, 2007).

According to NNI, “nanotechnology” is the control, comprehension, and reformation of material based on the hierarchy of nanometers to develop matter with essentially new uses and a new constitution. Considering this definition, nanotechnology is a novel approach in all sciences. Such an approach can be applied in geotechnical engineering in two ways: (1) in studying the soil structure in nanometer scale to gain a better understanding of soil nature, as well as in studying the performance of soils with different nanostructures; (2) in conducting soil manipulation at the atomic or molecular scale, which is facilitated by the addition of nanoparticles as an external factor to soil.

Soil stabilization is seen as a means of enhancing aspects of engineering and other elements, including the conductivity of hydraulics, compressibility, strength, and the density. Methods relating to soil stabilization can be categorized in numerous ways, including surcharge load, vibration, enhancing support for structures at hand with structure fill, grouting, and other techniques (Kazemian and Huat, 2010). Many techniques can be used for different purposes by enhancing some aspects of soil behavior as well as the basic makeup and potency of the soil (Edil, 2003). Ground treatment can enhance the bearing competence of the target soil, reduce the possibility of complete and disparity-based settlement, reduce in the during in which the settlement occurs, reduce the possibility of liquefaction with hydraulic fills or saturated fine sand, and reduce the hydraulic conduciveness, water retention, and water release of the soil (Kazemian and Huat, 2009). M.R. Taha (2009) has presented the Laboratory experiments to study the fundamental geotechnical properties of mixtures of natural soils and its product after ball milling operation. The product after ball milling process was termed nano-soil herein. The effect of nano alumina material on the volume change and desiccation crack behaviors for different plasticity index soils was investigated by (M.R. Taha, 2012) and his conclusion was the improve soil nano- alumina mixture enhance the beneficial changes in the engineering properties soil's. Zhanping You (2011) has showed that a large extent that nano-clay can be effectively used as a modifier to improve the mechanical properties of asphalt binder.

Stabilization Type:

Two stabilization types have been observed, namely, chemical and mechanical. Studies show that mechanical reinforcement with chemically stabilized soil can help improve properties, such as durability, stiffness or strength, and the capability to speed up soil treatment.

Chemical Stabilization:

Arora and Scott (1974) found several chemical mechanisms that are responsible for clay stabilization. Their

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work was further expanded by Borchardt (1984), who organized the chemical mechanism into a list, with the first six items being the most significant ones.

1. Cation exchange
2. Anion exchange
3. Ability to absorb
4. Fixation property
5. Ability to form new minerals
6. Property of cementation
7. Conversion of salts
8. Water film changes
9. Absorption ability of the water film
10. Using ions to enrich pore water
11. Changes in capillary forces
12. Changes in the clay minerals on the basis of electrical surface tension
13. Changes in electrical forces found in the particles
14. Changes in chemically bound water
15. Chemically bound water's absorption ability
16. Acid neutralization
17. Base neutralization
18. Proton exchange

Chemical stabilization is linked with the changes in the chemical make of the soil matrix. This can be achieved by heat, by using polymers of resins in the soil, by adding enzymes, by adding cement to the soil, or by changing the ionic or charge makeup of the soil.

Mechanical Reinforcement:

The engineering properties of clays can be enhanced through reinforcement. The main issue is the field mixability of fibers into clays, specifically in the case of plastic clays. Mixing fibers in highly plastic clay is difficult, but over time, clay loses its plasticity, allowing fibers to be mixed effectively. Polymers, plastics, word fibers, and glass fibers are some of the materials that can be used for mechanical reinforcement. As a standalone stabilizer, reinforcement is restricted to coarse-grained materials because of their high friction. Lime or cement can be used to stabilize clay soils.

Combinations:

Combinations can also be used to improve stabilization. One such combination involves the use of lime and cement, which has been studied extensively. Additional tensile strength is a favorable trait for the soil and combination techniques, which are utilized to achieve this.

Lime/Cement with Reinforcement:

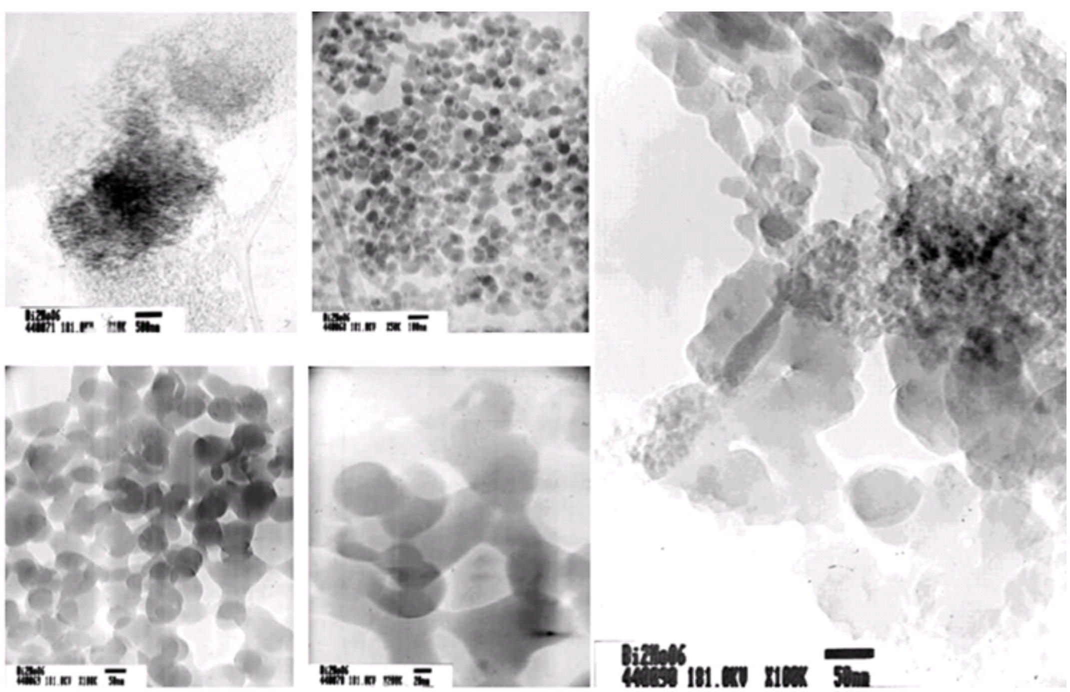
The use of fibers with lime or cement is based on the hypothesis that the fibers would lend immediate strength while lime or cement facilitates the curing process. Crockford *et al*. (1993) studied the process and asserted that the plasticity of clay soils improves significantly when fibers are used for the chemical stabilization of soils with lime or cement. The plasticity of clay is one issue that must be addressed when adding fibers to clay soil. Mixing fibers is difficult, particularly with the clay matrix. The reaction of lime with clay minerals decreases plasticity and allows the fibers to mix within the clay matrix. This decrease is reportedly due to the cationic exchange between calcium and the clay minerals. The applicability of this technique in the field was previously under question. However, based on the works of Freed (1990) and Grogan *et al*. (1994), fibers can be mixed with plastic fine soils with lime combination.

Chemical Stablilizers Including Cement/Line:

Three additives were found to be effective in improving the stabilization of lime-stabilized soils. Applying heat to the soil and lime mixture is the most commonly used method to increase soil strength. Ferris *et al*. (1991) used barium chloride combined with lime to improve soil strength. Using sodium as an additive has been found to improve the stabilization characteristics of lime- and cement-stabilized soils. Ruff and Davidson (1961) and Hurley and Thornburn (1972) studied the effect of sodium silicate on the stabilization of lime and cement, and found that sodium silicate helps improve soil strength. Moh (1962) also studied the effect of sodium additives on cement-stabilized clay and concluded that sodium additives increases the pH, reduces the calcium ion, and increases the ratio of sodium and calcium. These effects assist in dissolving soil silica, retard the precipitation process of calcium, and facilitates the formation of hydrated silica gel, thereby increasing the cementitious gel. Lees *et al*. (1982) studied sodium chloride as an additive using lime-stabilized soils such as kaolinite and montmorillonite. Increased strength was not observed in kaolinite soil compared with montmorillonite soils. In another study (Chandra 1987), commercial stabilizers were used with lime and cement. These products used their commercial names and their nature is unknown. However, additional research demonstrated that Melment and Plastiment A40 are polymeric in nature. Chandra concluded that "Some of the properties of clayey soils, such as low strength and high water absorption, which do not encourage their uses as a building material, can be improved and thereby making them more durable."

Investigation of Soil Nanostructure by Electron Microscopes:

Understanding the nature of materials and their structures has always been significant. The microscopic structure of fine soils can be used as an index in identifying the type of environmental processes and in estimating their resistance (Bennett, 1991). In observing soil structure on a small scale, some novel methods of investigations in the nanometer range and for particulate analysis have been suggested (Yalamanchili, 1998). Transverse electron microscopy (TEM), scanning electron microscopy (SEM), and atomic force microscopy (AFM) are direct methods for particulate imaging at the nanoscale level that provide information such as the dimension, shape, and morphology of particles (Kollensperger, 1999). SEM, invented in 1931 by Max Knoll and Ernst Ruska, provides a greater image of specimen using electrons. In this technique, a beam of electrons is focused vertically on the specimen. When the beam interacts with the specimen in vacuum, electrons and X-rays are emitted from the specimen. The detectors then collect X-rays, primary electrons, and electrons caused by the interaction of primary electrons with the specimen; these are subsequently converted into signals and then transferred to the screen to prepare the final image (Hawkes, 1998). SEM has been widely used to study the nanostructure of soil particles (Lin, 2006). In 1939, Siemens and Halska from Germany utilized TEM to obtain enhanced resolution and accuracy of images. TEM uses electron emission toward the specimen, similar to SEM; however, in TEM, the emitted electrons pass through the specimen and reach a phosphorous detector to provide a pattern of the specimen's structure (Wiliams, 2009). This device has also been employed for imaging soil nanostructure (Citeau, 2006). For instance, in a study carried out by Shephard *et al*. (Shephard, 1980) on marine clay sediments in North America, nanometer images of this region's soil were prepared by TEM for the evaluation of soil porosity. In addition, they showed that higher-ordered orientation of soil particles in the nanostructure leads to higher shear strength in comparison with clay sediments with random orientation. In recent years, AFM has been used in determining surface topography and studying surface forces. In AFM, a sharp tip connected to a cantilever scans the specimen's surface (Sarid, 1997). In geotechnics, AFM images are frequently used to study the surface morphology of soil nanoparticles, measure the adhesive force between soil particles, and to measure the friction angle between particulate soil particles (Michael, 2002).



a) b)

Fig. 1: Nano-SiO2 particles under TEM (Sobolev K. 2006).

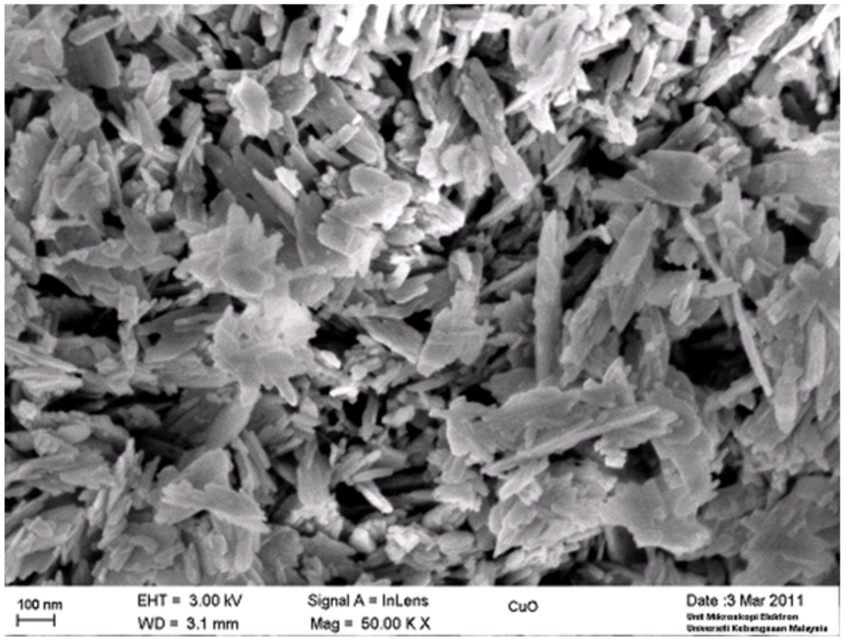


Fig. 2: Nano-CuO particles under SEM.

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 geometric dimensions down to the nanoscale completely modifies the behavior of the material.

Transitioning to the nanoscale 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 12 nm, 15% of the atoms are found at the boundary. For a size of 5 nm, 40% of the atoms will be on the interface. Figure 3, which shows the percentage of atoms at the surface of a hexagonal close-packed full-shell cluster, illustrates this effect.

For a low number of shells, the number of surface atoms becomes important, and the behavior of these atoms is completely different from that of the inner atoms. This situation accounts for the catalytic properties of nanocrystalline 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.

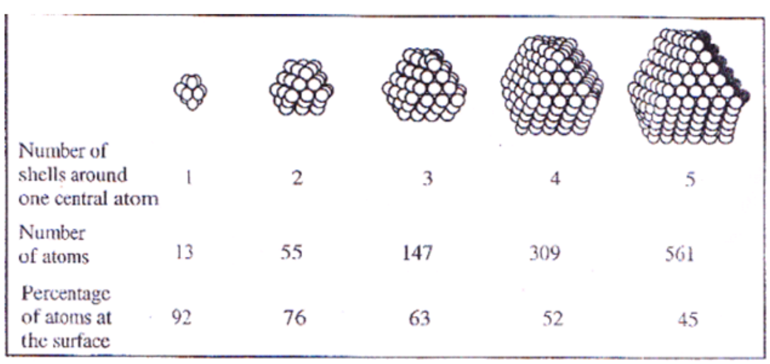


Fig. 3: Representation of hexagonal close packed full-shell clusters. (Hofmann, 2001).

Nanometric Additives and their Effects on Soil:

Nanoparticles influence the specific properties of soil. Generally, their properties become remarkably different when materials approach the nanoscale. The following list provides an overview of such changes:

1) At the nanoscale, a higher ratio of surface to volume and, in turn, a higher cation exchange capacity exists.

Therefore, they interact very actively with other particles and solutions such that very minute amounts may lead to considerable effects on the physico-chemical behavior and engineering properties of soil.
2) Gravity forces at the nanoscale can be disregarded. Instead, electromagnetic forces are dominant.
3) Instead of classic mechanics, quantum mechanical models are utilized for describing movement and energy at the nanoscale.
4) Random molecular movements are of higher significance at the nanoscale. Soils that contain nanoparticles with intraparticle voids usually exhibit higher liquid and plastic limits because of the following three reasons: (a) a higher specific surface leads to a larger amount of water encompassing the outer surface of particles; (b) the presence of nanopores causes water accumulation in these pores, hence resulting in an increase of the available water capacity in soil; (c) the nanostructure of soil particles is another factor for the increase in water accumulation capacity. The existence of nanofibers in soil usually enhances the thixotropic property of soil and increases its shear strength. In addition, these soils possess a much lower bulk density due to the occurrence of nanopores.

Discussion and Conclusion:

This paper provides an overview of the applications of nanoscience in geotechnical engineering, specifically nanotechnological approach in soil. This approach can be applied in geotechnical engineering in two ways: 1) in studying soil structure at the nanoscale and 2) in soil manipulation at the atomic or molecular level through the addition of nanoparticles as an external factor to soil. SEM, TEM, and AFM were used to study soil nanostructure. SEM images were obtained from the surface of the specimens; SEM images had a lower quality compared with TEM images. Different nanostructures exhibit different properties. Due to their smaller dimensions, nanoparticles possess a very high specific surface and react more actively with other particles in the soil matrix. The existence of even a minute amount of these nanoparticles can result in extraordinary effects on the engineering properties soil. This study found that nanoparticles influence the strength, permeability, indices, and resistance properties of soil.

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