ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 17 (2017) 639–650

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/acme

Review

Geotechnical properties of the soils modified with nanomaterials: A comprehensive review

Navid Ghasabkolaei [a], *Asskar Janalizadeh Choobbasti* [a], *Nader Roshan* [a], *Seiyed E. Ghasemi* [b,*]

[a] *Department of Civil Engineering, Babol University of Technology, Babol, Iran*

[b] *Young Researchers and Elite Club, Sari Branch, Islamic Azad University, Sari, Iran*

ARTICLE INFO

Article history:
Received 31 July 2016
Accepted 29 January 2017
Available online

Keywords:
Nanomaterials
Soil
Geotechnical engineering
Clay
Review study

ABSTRACT

In recent years, large steps have been taken in the field of nanotechnology, and many nanotechnology-based breakthroughs have been made in geotechnical engineering. It is apparent that nanomaterials will be used to improve the geotechnical properties of soils in the near future, extensively.

In this paper, we discussed previous studies on the use of nanoparticles in soil, their properties, their effects on soil and the equipment used in nanotechnology. A new categorization was introduced and the significant effects of nanoparticles on the properties of soil were studied. According to the new categorization, clay particles vary between 0.1 and 2 μm, while nanosol contains particles in the range of 1–100 nm.

1. Introduction

The ideas and concepts behind nanoscience and nanotechnology started with a talk entitled ''There's Plenty of Room at the Bottom'' by physicist Richard Feynman at an American Physical Society meeting at the California Institute of Technology on December 1959, long before the term nanotechnology was used [1,2]. Since then, various definitions have been proposed for nanotechnology. The National Nanotechnology Initiative (NNI) presented a comprehensive definition that includes the following three definitions: [3]

(1) Technology development and research at atomic, molecular, or macro-molecular levels on the scale of 1–100 nm;
(2) Creating and using structures, tools, and systems that have new properties and performances due to their small size or medium limit;
(3) Ability to control or manipulate at atomic levels.

Utilizing the properties of nanoscale material provides some characteristics, advantages and profits that are fundamental from medical, scientifical, environmental and commercial. Among the benefits that have been recognized to date are reducing energy consumption, economic savings, time savings, increased quality of products, all of which can contribute to increased quality of life and healthier lifestyles. They can also reduce our dependence on other advanced technologies and their higher costs and increase the national

* *Corresponding author.*
E-mail address: ghasemi.seiyed.e@gmail.com (S.E. Ghasemi).
http://dx.doi.org/10.1016/j.acme.2017.01.010

income. Unfortunately, the amazing effect of nanotechnology and its use have not been recognized well to date in geotechnical engineering. Perhaps this is due to the fact that nanotechnology studies are of interdisciplinary nature, which requires researchers to have wide range knowledge to understand the extended necessities of nanotechnology and to determine their roles in this new and exciting field [4]. However, in recent years, some significant steps have been taken to evaluate the potential uses of this technology in geotechnical engineering and given the promising results of these studies, it should not be surprising when this technology is embraced and utilized in geotechnical engineering.

In this paper, we describe the "nanosol" concept, which is a new classification of soil. Then, we discuss the equipment used to analyze the structure of soil and some cases in which nanoparticles can be used to improve the geotechnical properties of soil. Therefore, nano particles can be entitled as an additive for stabilization of soils.

2. Soil classification based on nano-approach

Soil is any uncemented or weakly-cemented accumulation of mineral particles [5] with size ranging from as small as 1 nm to as large as 75 mm [6]. Such a wide range of particle sizes has made soil one of the most complicated materials to study, understand, model, and utilize. In classical geotechnical engineering, four categories of soil are generally recognized, i.e., gravel, sand, silt, and clay; the dimensions of which are provided in Table 1 [7].

Although this classification has solved two problems related to soil mechanics. First, as the sizes of the particles decrease to the nanoscale, their properties can change dramatically. Second, according to the classical definition, clay particles include particles smaller than 2 μm, which means that the sizes of clay particles range from 1 nm to 2 μm. Therefore, the ratio of the size of the largest particles to the size of the smallest particles is $2 \times 10^{-6}/1 \times 10^{-9} = 2000$, which is much greater ratio than for other fractions. Thus, Zhange [7] proposed the new range of 0.1–2 μm for clay particles, giving them a ratio of 20. In so doing, the ratio was changed from 2000 to 20, which is about the same as the ratio for other fractions. Similarly, in the proposed new definition, the sizes of nanoparticles were designated to be in the range of 1–100 nm, giving them a ratio of 100. Thus, a new category of particles, called "nanosol," was devised to define these soil nanoparticles that have properties that are remarkably different from those of clay [7].

Table 1 – The size range of soil particle [7].

Particle	Lower limit	Upper limit	Ratio
Gravel	4.75 mm	75 mm	15.8
Sand	0.075 mm	4.75 mm	63.3
Silt	2 μm	75 μm	37.5
Clay (classical)	1 nm	2 μm	2000
Clay (proposed)	0.1 μm	2 μm	20
Nanosol	1 nm	100 nm	100

3. Applying nanomechanics in geotechnical engineering

The concept of nanomechanics is related to geotechnical engineering for the following reasons:

- *Soil and rock minerals are nanomaterials*: nanoparticles exist in soil environment, including smectite, imogolite, halloysite, palygorskite, sepiolite, allophane, hematite, and goethite [7].
- *Nanomechanics can be used to gain a better understanding of the mechanical behavior of soil and rock (e.g. friction, creep, thermal effects, and chemical effects)*: nanoparticles interact very actively with other soil constituents (including the liquid phase, cations, organic matter and clay minerals) due to their exceptionally high specific surface area (SSA) (i.e., the total surface area per unit mass) and reactive surfaces with charges, and thus they have profound influence on the microstructure and the physical, chemical and engineering properties of soils, even when they represent only a very small weight fraction of the material [7].
- *Nanomechanics can predict the behaviors of geotechnical materials in special conditions*: The soils are natural materials that possess complex physical and chemical properties, so predicting the behavior of soil definitely is challenging, even with modern geotechnical engineering techniques [8].
- *The interaction of soils and rocks with fluids (e.g., weathering) is a nanoprocess*: Some nanoparticles are porous and contain intraparticle-nanoscale voids. The presence of nanoporosity significantly increases the SSA and hence the absorption capacity (e.g., water retention, organic absorption) and also reduces bulk density. Therefore, porous nanoparticles can influence soil properties very dramatically, even when they are present as a very small weight fraction [7].

Clay is a nanomaterial and the behavior of its particles is controlled by nanomechanics [9].

4. Equipment used to study the nanostructure of soil particles

The microscopic structure of fine-grained soils can be used as an index to identify diverse environments and evaluate their strength [10].

New methods have been proposed for observing the structure of soils at the nanometric scale. The transmission electron microscope (TEM), scanning electron microscope (SEM), and atomic force microscope (AFM) are among the direct methods for taking images of nanoscale particles, and they provide information concerning their dimensions, shapes, and morphologies [11,12].

SEM was invented in 1931 by Knoll and Ruska. It provides larger images using electrons. In this method, an electron ray perpendicularly shines on the specimen. As an interaction between the ray and specimen in vacuum, electrons and X-rays are emitted. Sensors receive the emitted X-rays, the initial electrons, and the electrons that result from the interactions of the initial electrons. The sensors convert them into signals and transmit the signals to monitors that provide the final image