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A REVIEW OF IMPROVEMENT GEOTECHNICAL CHARACTERISTICS BY NANO ADDITIVES

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Abstract

This paper reviews and discussed soil stabilization by using the nanomaterials as additives; analysed their effect on soil. With the urban development and the rapid increase in population, including projects to expand cities, the need has become urgent to implement various types of projects such as buildings, dams, highways, and others. The foundation soil on some sites is weak and do not have the necessary and required engineering properties. Because of that, the soil properties should be improved from "bad" soil to a better foundation soil, increasing the shear strength parameters, reducing soil compressibility and reducing soil permeability. Therefore, soil improvement is an essential solution to enhance it characteristics. Nanomaterials can be described as materials with particles of at least one dimension between 1-100 nm. In recent years, nanotechnology has been used for improving the geotechnical properties of soils, and it has given a significant advantage in this field. The objective of this review article is to analyse some of the publications using nanomaterials as additives to the soil.

Key words: *nanoparticle, soil stabilization, nano-MgO cement, nano-clay.*

INTRODUCTION

Soil is natural mineral particles that can be separated into relatively small pieces which have been formed by breaking down the rocks, as a result of weathering processes such as water, air, or organic materials (formed by the decomposition of plants). In another hand, it is considered the oldest and the cheapest material used as a construction material. There is an increasing need to use the marginalized sites for construction and the implementation of new projects, which include projects to expand cities and infrastructure projects and others. Some of those sites contain weak soils which don't have the necessary and required engineering properties. For this reason, the soil properties should be improved and stabilized, in order to reach the level of acceptance in the engineering community and transform from weak soil into a good foundation soil.

The necessity of foundation soils improvement and stabilization was admitted since the beginning of the constructions, the solutions and technologies advancing in time (Ivasuc et al., 2014). Soil stabilization is defined as the method used to change the soil's texture and improve its geotechnical properties such as increase the shear strength, reduce the permeability and compressibility, and thus increase the bearing capacity of the soil. Two stabilizations type have been observed, called, mechanical and chemical stabilization (Patel, 2019).

Mechanical stabilization is the physical process of improving the ground by changing its gradation, including soil compaction by using rollers, vibration techniques, and rammers, or by incorporating other physical properties like barriers and nailing (Afrin, 2017).

Chemical stabilization is a process of mixing chemical additives (binder materials) to the soils to improve it engineering properties. This method can be achieved in the site or in the laboratory, and it is divided into two parts, traditional and non-traditional additives (Zahri et al., 2019).

Physical stabilization is done by the modification of the grain size distribution of a soil by mixing it with another soil; chemical stabilization is done by altering the soil structure by mixing it with some chemicals (Olinic et al., 2015). Examples of conventional additives are cement, lime, and fly ash. When

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they exposed to water, a chemical change occurs, which leads to improved soil properties, reducing swelling, improving shear strength, and avoiding the harmful effects of wetting and drying. Cement is one of the oldest materials are added to the soil to improve its properties due to its high efficiency. It's suitable for a wide range of soils because its reaction doesn't depend on the soil type but appears when in contact with water. Also, the use of cement has many limitations. For example, the content of the organic material must not exceed 2% for the soil wanted to mix it with cement, contain a small amount of clay, and be without salts such as sulphate salts that affect the formation time of the cement soil (Ikeagwuani et al., 2019).

Non-traditional soil stabilization additives like nanomaterials consist of a wide range of chemical agents that differ in their composition and the mode they react with the soil. Nanotechnology is the term is given to managing matter at a very small scale between (1-100) nano-meter scales. Also, it is the branch of science, engineering, and technology conducted in at least one dimension is in the nano-meter scale. Nanotechnology is involved in many domains, including industrial, engineering, medicinal, and energy uses. Recently, it used several nanomaterials in the civil engineering sciences, to enhance their performance such as steel, concrete, glass, wood, coating, and structural monitoring which made significant and rapid progress in the last years. Nanotechnology in geotechnical engineering can be seen in two ways: the soil's structure at the nanoscale, secondly at the atomic or molecular level through the addition of nanoparticles as an external factor to the soil (Majeed et al., 2013). Nanomaterials can be described as materials with particles of at least one dimension between 1-100 nm. Nanomaterials can occur naturally, be created as products of combustion reactions, or be produced purposefully through engineering to perform a specialized function. Nanomaterials can have different physical and chemical properties than their bulk-form counterparts. They can exist in single, aggregated, or agglomerated forms with spherical, tubular, and irregular shapes. The idea of using nanomaterial to improve soil properties comes from the inter-particles concept. Because of their small dimensions and the high specific surface area, they are more active and affect the soil matrix. The difference in the particle size contributes to inter-particle filling or interlayer filling, which reduces the void ratio, which will make the soil more resistant to the applied load.

The idea of modifying the engineering properties of the soils is not new. Some of the principles of soil improvement like dewatering, densification, and the use of admixtures have excited thousands of years. In Mesopotamia the area between the Tigris and Euphrates rivers, now Iraq, they use in the ancient time the wood and straw inclusion mixed with mud for “Adobe” (Nicholson, 2014).

Also, from the Chinese civilizations, the written works describe the use of the column and timber inclusions. An early report on soil improvement in 1978 was that of the ASCE Committee on placement and improvement of soils which it was noted: “Soil, nature’s most abundant construction material, has been used by man for his engineering works since prior to the beginnings of recorded history” (ASCE, 1978). In the nineteenth century 19th during the great industrial revolution and the development of the machinery and equipment has a greater effect on increasing the efficiency of the ground improvement techniques and decrease of its problems. In Europe, in the twentieth century 20th, and to our present days many ground modification techniques have been developed by contractors during their implementation of projects as well as geological institutions.

MATERIALS AND METHODS

This paper reviews and discussed soil stabilization by using the nanomaterials as additives and analysed their effect on soil. A series of bibliographic references, which are reported below, were analyzed.

Jarrahzadeand Bajestan (2010), studied the change of clay structure by nanotechnology due to soil stabilization in both urban and rural roads. They have suggested a new and cheaper method to improve soil properties than usual methods. Their studies are based on changing clay structure by nanotechnology. It will change to be hydrophobic after it is hydrophilic. They used several sheets made of silica and alumina. The water is strongly bound to the surface of the clay particles and cannot be removed by sunlight drying or using ovens. Still, it can be removed easily by using chemicals called con-aid, which causes an ion exchange and takes place on the surface of the clay. On the other hand, the adsorbed water will displace or remove to make the clay in a hydrophobic state. Their results show that nanocomposites of clays can reduce the thickness of the asphalt from 27 cm to 5 cm.

Majeed et al., 2012, studied the effect of nanomaterial treatment on the geotechnical properties of Penang soft soil. A different nanomaterial, nano-MgO, nano-clay, and nano-Cu, with proportions ranging from 0.05% to 1%, and added to soft soil samples from the State of Penang to investigate and study their effect on geotechnical properties. Atterberg limits, linear shrinkage, dry unit weight, moisture content, and shear strength of the soil were determined, and it is decreased with increasing the percentage of nanomaterials. On the other hand, the increase of nanomaterials due to an increase in the maximum dry density generally indicates soil improvement. Also, the optimum moisture content increased, and the results showed that the compressive strength of the soil increased with nanomaterials.

In 2014, Majeed et al. studied how to modify and stabilize soft soil by using nanomaterials. Three types with less than 1% are used in this research: nano-magnesium, nano-copper, and nano-clay. Nanomaterials were added to the soft samples collected from two different sites in Malaysia. The results show that nanomaterials' addition decreases the linear shrinkage, liquid limits, plastic limit, and plasticity index. On the other hand, the dry maximum density and the compressive strength of the soil increase with increasing the amount of nanomaterial and decreasing the optimum water content.

Babu and Joseph, 2016, presented an experimental work. They studied the effect of adding different nanomaterials nano Fly ash and nano Titanium Dioxide (TiO_2) with a proportion (0.5%, 1%, 1.5%, 2%) on the samples of soft soil collected from the Nedumudi region of Kuttanadu. Their results showed that the increasing amount of nano fly ash and TiO_2 decrease the liquid limit and plastic limit by around 60%. Optimum moisture content decreased by 5.2%, the maximum dry density increased by 2.94%, and the shear strength increased to twice the original value. Also, they noticed that the nano fly ash is better than TiO_2 for reduction settlement at the optimum percentage of nano fly ash and Titanium Dioxide (67%, 60%), respectively.

Priyadharshini and Arumairaj, 2015, investigated the effect of adding three types of nanomaterials, nano-Al_2O_3 and nano-MgO and nano-clay, with a different percentage to soft clay samples, consistency between (0.25-0.5) and UCS between (25 to 50) kN/m^2 experimentally. Their model studied the conducted in a steel tank of (30 x 30 x 30) cm with (6 x 6) cm square footing to determine the load-carrying capacity of the footing for soft clay with nanomaterials. The results showed that the increasing amount of nano-Al_2O_3 and nano-MgO decreased Atterberg's limits and the increase in nano clay amount increase the Atterberg's limits. The optimum moisture content increases when the amount of nano-Al_2O_3 and nano clay increases, and vice versa for nano-MgO. Also, increasing the amount of nano-Al_2O_3 and nano clay leads to a decrease in the maximum dry density, and an increase in the amount of nano-MgO leads to an increase in the maximum dry density. The unconfined compressive strength increases up to 43% for 0.75% of nano-Al_2O_3 and 41% for 0.3% nano-MgO and 48% for 1% nano-clay. Their study also found that nano-MgO reduces the settlement better than the nano clay and nano-Al_2O_3.

Subramani and Sridevi, 2016, studied the effect of nanomaterials nano-cement and nano-clay, with the various percentages ranging from (0.5% to 2%) on the soft soil (peat). Consistency limits, compaction characteristics, and compressive strength are determined in their investigation. The results showed that the increase of nanomaterials increases the maximum dry density, indicating improvement in geotechnical properties. The unconfined compressive strength increases when one increases the number of nanomaterials and the plasticity index decrease with an increase in the number of nanomaterials. Also, they found that when combined, addition (1% nano-clay and

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1% nano-cement) gave maximum strength compared with 2% nano-cement and 2% nano-clay.

Mostafa et al. (2016) investigated the stabilization of subgrade pavement using nanomaterials (nano-silica and silica fume) with various amounts. They used 1, 2 and 3% for nano-silica 5, 10 and 15% for silica fume while used 2, 4, 6 and 8% for lime. Their study was to estimate the physical and mechanical properties using the Atterberg limits test, direct shear test, free swelling, modified proctor test, unconfined compressive strength, and California bearing ratio. They did unconfined compressive strength and free swelling test after two curing periods, 7 and 28 days. The results showed that the maximum dry density decreased, and the optimum moisture content increased for all user activities, the unconfined compressive strength increased; also, they noticed that the maximum drop in free swelling was when used a combination of (8% lime + 15% silica fume) and (8% lime +3%nano silica).

Majeed et al., 2016, analysed and studied the geotechnical properties of the soft soil after mixing it with a different percent of nanomaterials (nano-MgO, nano-Al_2O_3, and nano-Cu_2O). They determined the compressive strength, dry unit weight, and moisture content. They found that the soft soil's compressive strength and dry density increased with increasing the number of nanomaterials; at the same time, the moisture content decreased.

Naval et al., 2017, studied the effect of different percent of nanomaterials, 0.5%, 1.0%, 1.5%, and 2.0%, from nano-Al_2O_3 and nano-MgO on the properties of expansive soils. They found out that the swelling potential of the soil decreased when the number of nanomaterials increased from 0 to 2%. This decrease is due to a decrease in the values of liquid limit, plastic limits, and plasticity index of the soil. This may be a structural unit of kaolinite mineral composed of silica and gibbsite sheets. When water enters, it causes swelling, in the other hand, the additional nanomaterials led to fill the tiny pores, and therefore reduce the amount of water into these units of the structure, thus decreasing the swelling of the minerals. Also, the maximum dry density increases with increasing the number of nanomaterials.

Rajendiran's and Vadivel's, 2016, study was made on a neat cementitious grout with a w/c ratio 1.20 incorporated with different percent (0%, 0.10%, 0.50%, 1.0%, 1.50%) of nano-silica (SiO_2). They found that the bleeding potential decreased with an increase in the amount of nano-silica. On the other hand, they found that the neat cement grout had unstable high bleed ability. Also, the specimen that was treated with nano cementitious grouted was found more impermeable to water, and compressive strength increased 1.6 times that treatment with neat cement grouted. The nano-silica (SiO_2) added cementitious grout shows improvement of engineering properties as well as the fresh mixed grout properties.

Taha and Ashraf, 2018, studied the effect of Carbon Nanomaterials (carbon nanotube was compared to carbon nanofiber) on sandy clay soil improvement. The maximum percentage of nanomaterials was used in their study was 0.2%. They found that the pH, the specific gravity, and the maximum dry density of the mixture soil-nanomaterials increase with the addition of nanomaterials. The results of the hydraulic conductivity test showed that nanomaterials reduce the value coefficient of permeability, and the sample of the soil treatment with carbon nanofiber (CNF) appears a higher reduction of hydraulic conductivity when compared with the use of carbon nanotube (CNT).

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Table 1. Summary of the experimental studies on improving soils with nanomaterials

Author	year	Nanomaterial type	Soil type	Results
Jarrahzade et al.	2010	silica and alumina	Clay	Nanocomposites of clays have the ability to reduce the thickness of the asphalt from 27 cm to 5 cm
Majeed and Taha	2012	MgO, nano-clay, Cu	Soft soil	increase in the maximum dry density and compressive strength of the soil increased
Majeed and Taha	2014	nano-magnesium, nano-copper, and nano-clay	Soft soil	decreases the linear shrinkage, liquid limits, plastic limit, and plasticity index
Babu and Joseph	2016	Fly ash and nano Titanium Dioxide (TiO_2)	Soft soil	decrease the liquid limit and plastic limit by around 60%. optimum moisture content decreased by 5.2%, the maximum dry density increased by 2.94%, and the shear strength increases to twice the original value
Priyadharshini et al.	2015	Al_2O_3, MgO, nano-clay	Soft clay	the increasing amount of nano Al_2O_3 and nano MgO decrease in Atterberg’s limits and increase in nano clay amount increase the Atterberg’s limits. The optimum moisture content increase when increasing the amount of nano Al_2O_3 and nano clay, and vice versa for nano MgO. The unconfined compressive strength increases up to 43% for 0.75% of nano Al_2O_3 and 41% for 0.3% nano MgO and 48% for 1% nano clay
Subramani et al.	2016	Nano-cement and nano- clay	Soft soil-peat	increases the maximum dry density, the unconfined compressive strength increases, and the plasticity index decrease
Mostafa et al.	2016	nano-silica and silica fume	Subgrade pavement	the maximum dry density decreased, the optimum moisture content increased, and the unconfined compressive strength increased
Majed and Taha	2016	MgO, Al_2O_3, Cu (2)O	Soft soil	the compressive strength and the dry density of the soft soil increased, and the moisture content decreased
Naval et al.	2017	Al_2O_3, MgO	expansive soils	the swelling potential of the soil decreased, decrease in the values of liquid limit, plastic limits, and plasticity index of the soil, and the maximum dry density increases
Vadivel and Stalin	2016	Nano-silica (SiO_2).		compressive strength increases 1.6 times
Taha and Ashraf	2018	Carbon Nanomaterials	Sandy clay	the PH, the specific gravity, and the maximum dry density of the mixture of soil-nanomaterials increase and reductions in the value coefficient of permeability

RESULTS AND DISCUSSIONS

SEM SCANNING ELECTRON MICROSCOPY AND TEM TRANSMISSION ELECTRON MICROSCOPY

Understanding the nature and the structure of materials has always been significant. Scanning electron microscopy and transmission electron microscopy is a high-resolution electron microscope used for the measurement of nanoparticles, which can observe the specimen surface and resolve down to 10 nm. And it's considered a direct method to provide information about the particles at the nanoscale level like the shape, the dimension, and the morphology of the particles (Figures 1 and 2).
By this technology, we can observe if there is a change in the soil matrix and/or the formation of the bonds between the particles (Goldstein, Joseph, 2017).

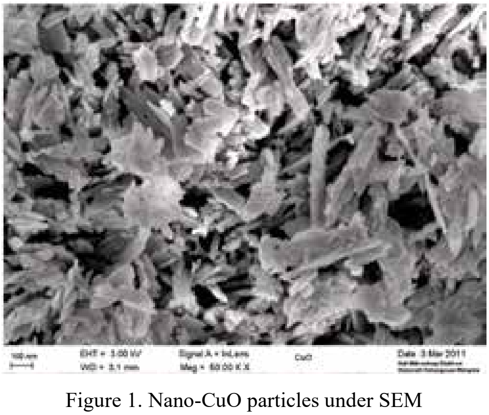

Figure 1. Nano-CuO particles under SEM (Majeed and Taha, 2016)

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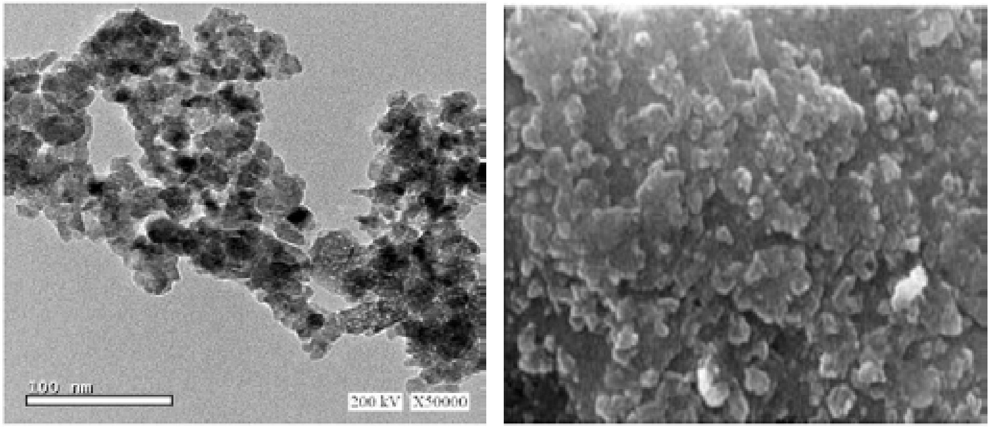

a. b.

Figure 2. a) SEM of CuO nanoparticles b) SEM of CuO nanoparticles (Barbara et al, 2015)

X-RAY DIFFRACTION

X-ray Diffraction is a rapid analytical technique mainly used for phase identification of a crystalline structure also can give information about the cell dimension. It is considered one of the most important tests when studying stabilized soil to find out the changes in the phase mineralogical reaction. By x-ray diffraction, it can be seen if there is an effect of the materials additives on the soil samples (Figure 3) (Alfaryjat et al., 2015).

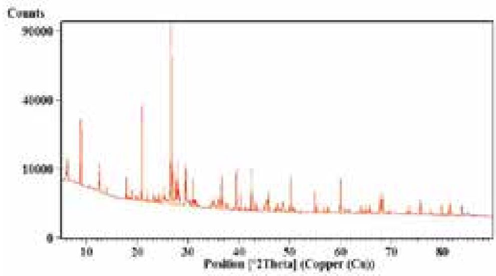

Figure 3. Soil treated with 0.75% nano-MgO (Al-Rubaye et al., 2021)

NANOPOWDER/CEMENT DESCRIPTION AND APPLICATIONS

Aluminum Oxide (Al_2O_3) is a white powder consisting of alpha phase aluminium oxide. It is used in many applications such as oxide ceramic, nanocomposites materials, biomaterials, catalyst support, and wear resistance additives also has been used in recent years in various engineering projects, as well as in improving the properties of soft soils and making them suitable for many engineering requirements (Table 2, Figure 4). The SEM microscopy measurement for nano-Al_2O_3 can by observed in Figure 7.

Table 2. Properties of nano- Al_2O_3

Parameter	Value / comment
Formula	Al2O3
Colour	White
Purity	99.9 %
density	3.95 g/cm^3
D50	10-50 nm
Specific surface area (SSA)	≤ 50 m^2/g

Figure 4. Nanoparticle of Al_2O_3

Magnesium oxide (MgO) is a fine white powder made up primarily of magnesium oxide particles ranging from (10 to 30) nm in diameter (Table 3). It is used for refractory materials, electric insulation, dehydration, fuel additive, and fire retardant, in addition to its multiple uses in construction. The SEM microscopy measurement for nano-MgO can by observed in Figures 5 and 8.

Table 3. Properties of nano- MgO

Formula	MgO
Colour	White
Purity	99.9%
Bulk density	0.1 g/cm^3
D50	10-30 nm
Specific surface area (SSA)	>50 m^2/g
Melting point	2.852°C
Boiling point	3.600°C at 1.013 hPa
Density	0.13-0.16 g/cm^3
Water solubility	Insoluble

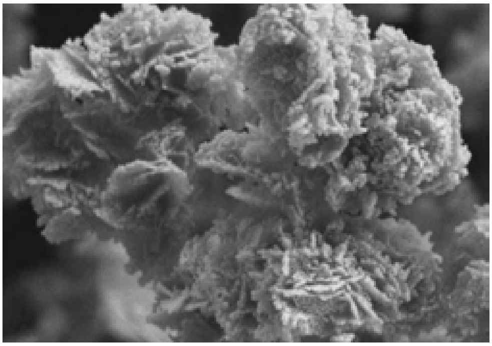

Figure 5. SEM measurement
for nano- MgO (Majeed, 2013)

Zirconium Oxide (ZrO_2) is a white powder with purity reached 99.9% and a density of 5.6 g/cm^3 with particle shape nearly spherical.

It was used in many applications, such as improving the characteristics of cement mortars, pigments and glazes, ceramic, artificial jewellery, fire retardant, abrasives, electronics, pyro-optics, insulation, energy storage, and high-stress (Figure 6).

The SEM microscopy measurement for nano-Al_2O_3 can by observed in Figure 9.

Figure 6. Nanoparticles of ZrO_2

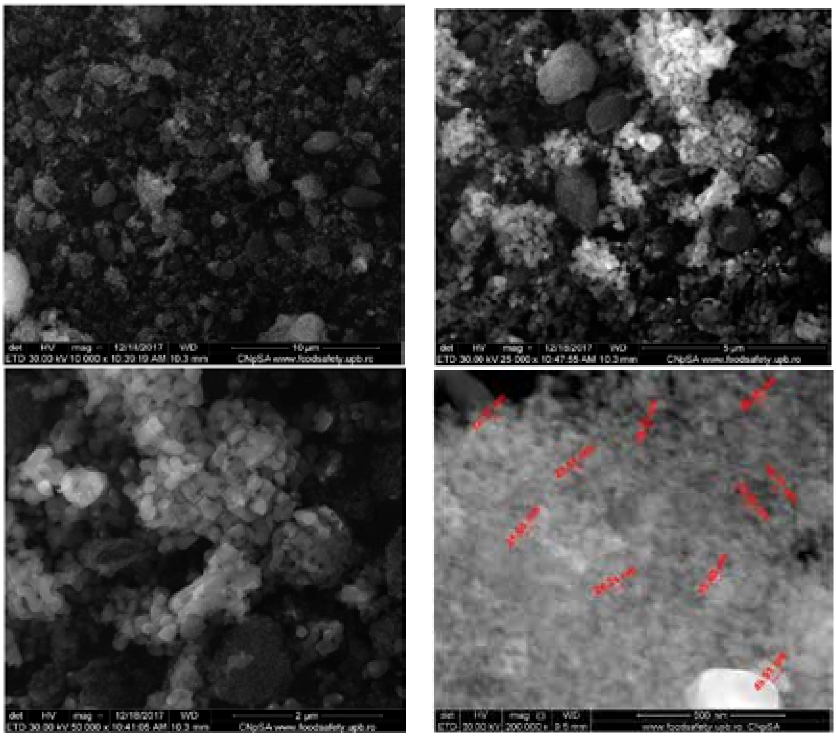

Figure 7. SEM measurement of nano-Al_2O_3 (Alfaryat et al., 2019)

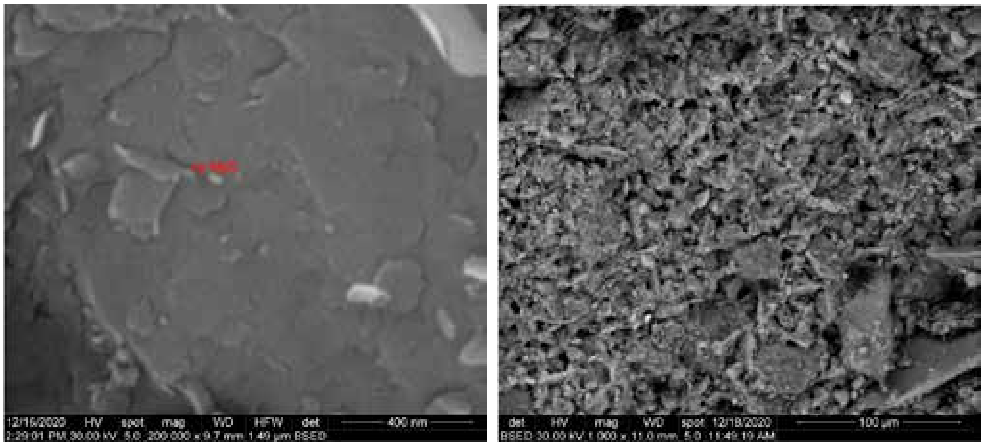

Figure 8. SEM microscopy measurement on soil samples treated with nano-MgO (Al-Rubaye et al., 2021)

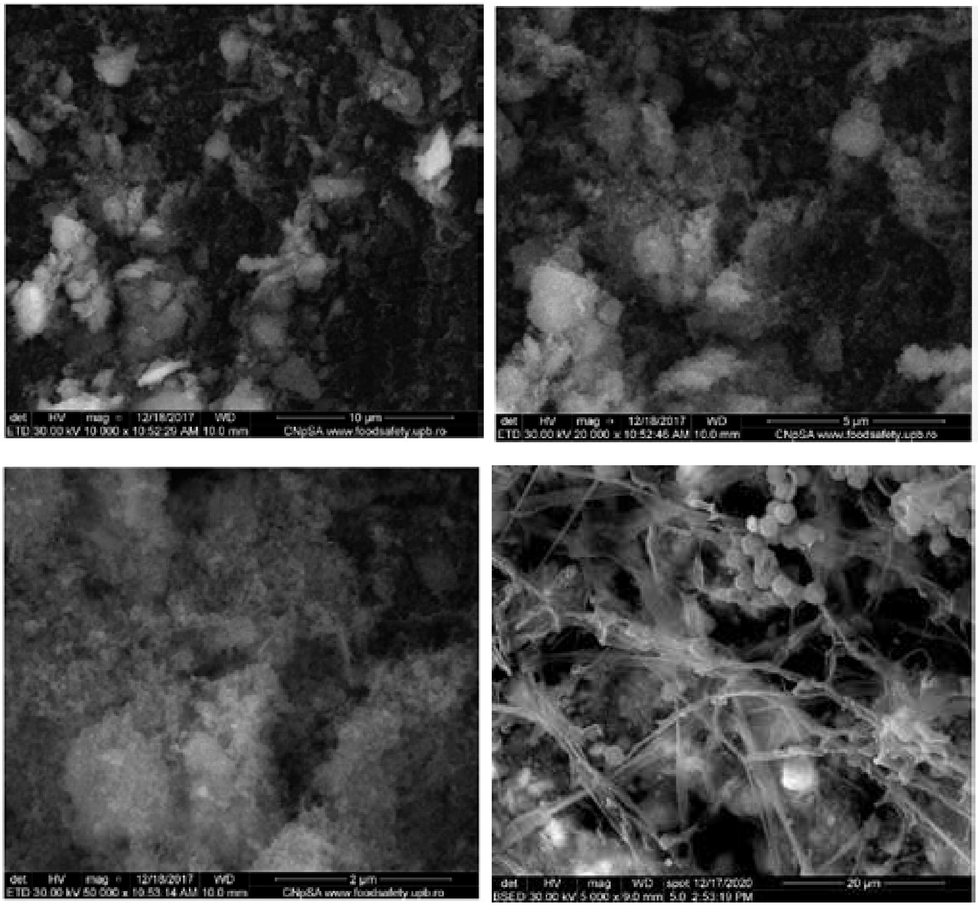

Figure 5. SEM measurement of nano-ZrO_2 (Alfaryat et al., 2019)

The Titanium Dioxide Nanoparticles' (TiO_2) size ranges from (10-30) nm, and they are transparent, chemically stable, and weather resistant. It has several uses in the field of construction, especially when added to the concrete to improve its properties or adding it to the paints and windows for sterilization purpose, as well as adding it to the surfaces of the external building to reduce and prevent damage to it, thus reduce the maintenance times and costs. Also, in the field of geotechnical engineering, it has been used to improve the engineering properties of the soil.

Cement is one of the oldest binding materials since the invention of soil stabilization technology, which is added to the soil to improve its properties. The reaction of the cement does not depend on the mineral of the soil, and it appears in any soil with water. It is, in general, an adhesive material that substance in the form of a powder when mixed with water, a hard mass is formed due to the presence of the chemical mixtures of cement compounds with water which results in a gel-like substance with a high surface area, often called cement. There are many applications on the soil-cement like roads, airports, shoulders, storage areas, and subbases for rigid pavement. The SEM microscopy measurement on soil samples treated with cement can by observed in Figure 10.

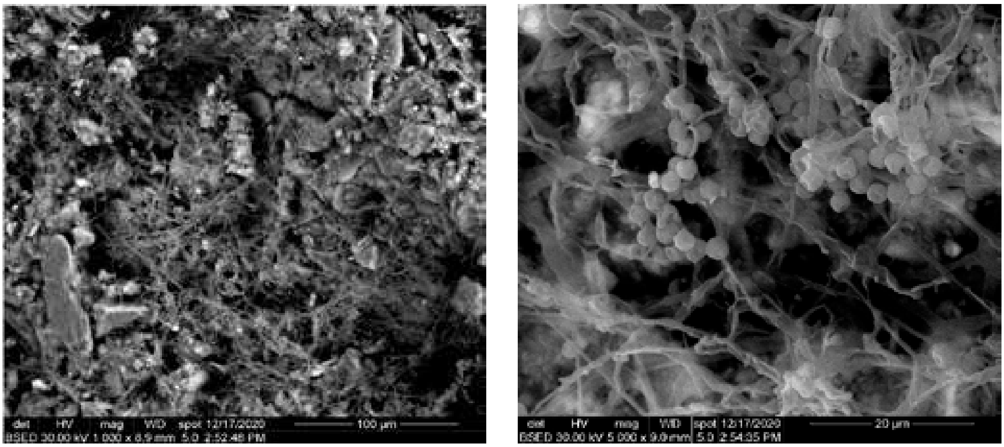

Figure10. SEM microscopy measurement on soil samples treated with cement (Al-Rubaye et al., 2021)

CONCLUSIONS

This paper reviews the nanotechnology and nanomaterials as additives to the soil and discusses the effects and results on the treated soils' physical, mechanical, and chemical properties.

Many types and different percentages of nanomaterials were used in the research, such as nano-clay, nano-Al_2O_3, nano- MgO, Nano Titanium Dioxide (TiO_2), nano-silica (SiO_2). SEM, FEM and XRD were used to study the soil nanostructure. Because of the small particle size and a higher cation exchange capacity can be active and react on the soil matrix. This state-of-the-art study found that soil improvement using nanomaterials depends on the type and the amount of these materials. The addition of nanoparticles to the soil improves its physical and chemical properties.

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