Contents

1 EXPERIMENTAL TESTS – RESULTS AND DISSCUTIONS

1.1 Introduction

The overall aim of this chapter is to present and investigated experimentally the effects of using nanomaterials (Nano-MgO and Nano-Al_2O_3) as additives on the physical, mechanical, and chemical properties of the soils. Soil samples, which are used in this research, were collected from two different sites in Romania. The first soil was collected from the church Adormirea Maicii Domnului, located in commune Perisoru, Calarasi county approximately 120 km to the East of Bucharest, the second soil was from commune Viisoara Sud, Vaslui county located approximately 300 km in the north of Bucharest. These sites are need for soil improvement due to very low soil consistency, low shear strength and poor mechanical soil parameters. Soil improvement is the term to describe any modification in the soil texture by using mechanical, chemical, and physical methods [1].

There are a number of ground improvement techniques that can be used to improve the properties of the soil as compaction, stone columns, grouting, soil mixing, and geosynthetics. Nanotechnology is the branch of science, engineering, and technology conducted in at least one dimension in the nanometer (1-100) nm [2].

In the recent years, this technology has been used in the geotechnical engineering field and many researchers found that the nanomaterials might have an influence on the geotechnical properties of the poor soils and may can help to improve them. Two different types of nanomaterials were used in this study, which are namely Nano-MgO, with different percentages (0.5%, 0.75%, 1%, and 2%), and Nano-Al_2O_3 with percentages (0.5%,1%, and 2%). By scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD) we check if there are any changes in the soil matrix and the minerology of the soil, after mixing with nanomaterials. The main aim of this study was to determine the evolution of geotechnical parameters for soils treated with different types of nanomaterials and to study their effect on the soil texture. The improved soils have been experimentally investigated and tested in the laboratory for soil consistency, shear strength and compressibility.

1.2 Nanomaterials (nanoparticles)

Nanomaterials are defined as chemical materials that are smaller than 100 nm. The nanotechnologies idea was suggested by Richard Feynman for the first time in 1959 [3]. The definition of nanomaterials is given also according to the European Commission, at least half of the particles size distributions of nanomaterials must have a particle size of 100nm or less [2]. After that, this technology developed and used in all branches of sciences such as pharmacological, biotechnological, engineering, and pure technological. These materials are considered and represented a connection between bulk materials and molecular structures, the properties of nanoparticles is differ from those of bulk forms for the same materials [4]. Nanomaterials can occur naturally, can be found in volcanic ash, ocean spray and even biological matter or be created as the by-products of combustion reactions [5]. In additional, they are a kind of unique materials due to their huge surface area, which outweighs the contributions made by the material's modest bulk [6]. The size of the nanoparticles may affect the chemical and physical properties of the bulk materials. anyhow, As the particle size of a material approaches the nanoscale and the percentage of atoms at the surface of a material increases, its characteristics make significant.

1.3 Methodology

1.3.1 Experimental procedures

The Preparation of the soil-nanomaterials mixtures with a different percentage of (Nano-MgO and Nano Al_2O_3) and study their effects on the geotechnical properties of the soil samples, are the main focus of this research. All the treated soil samples were prepared in the laboratory, Figure 1 shows the steps of the experimentally work and laboratory tests.

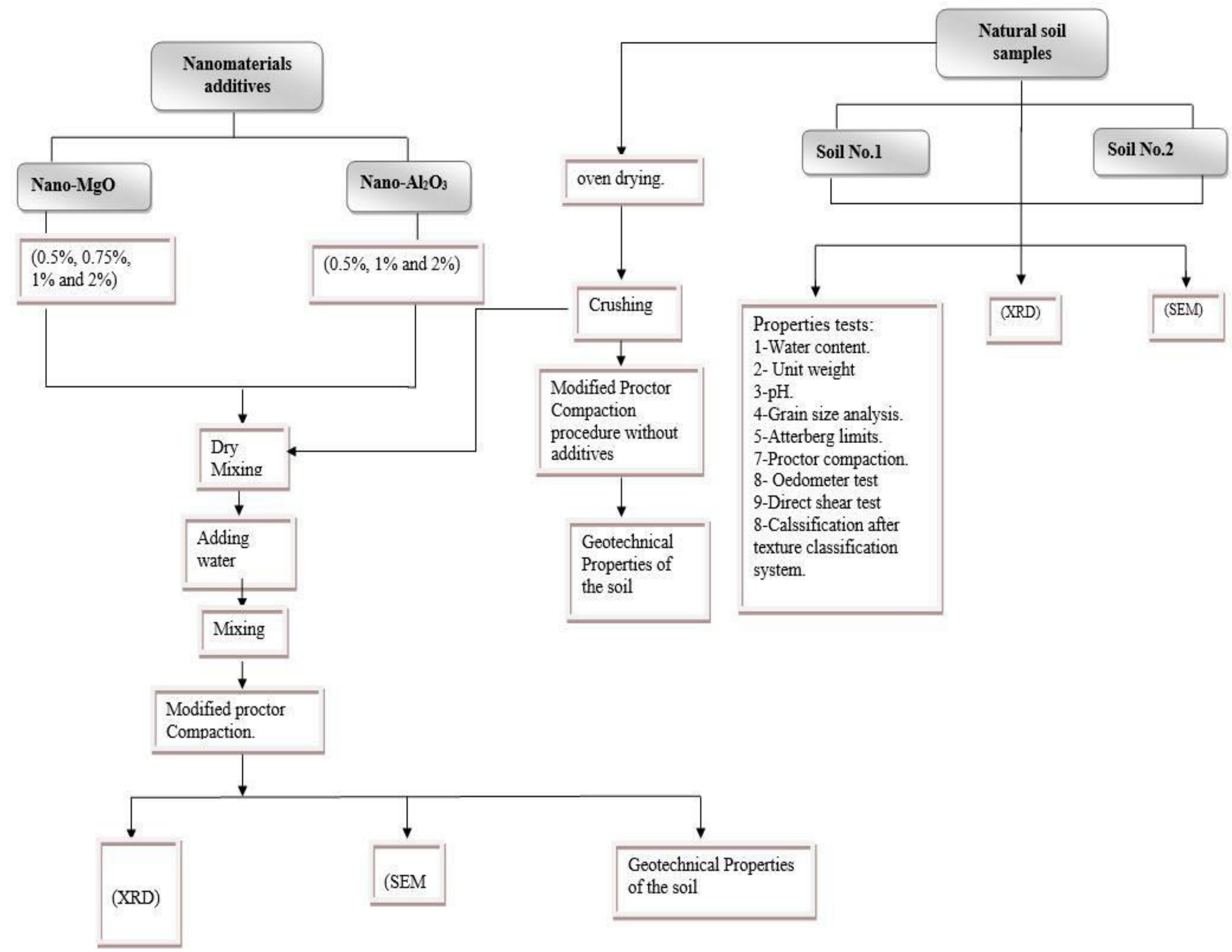


Fig. 1. The steps of the preparation of soil-nanomaterials mixtures and laboratory tests

1.3.2 Material properties

Soil samples were used in this research collected from two different sites in Romania. The first soil was collected from the backyard of the church Adormirea Maicii Domnului, located from commune Perisoru, Calarasi county approximately 120 km to the East of Bucharest. The second soil was from commune Viisoara Sud, Vaslui county located approximately 300 km in the North of Bucharest. The oil samples were classified according to texture classification system. The sample soil is a yellowish silty clay, soft (wetted loess). Figure 2 shows the locations of the soil samples collected.

Fig. 2. Location of soil sample collection site (http://www.googleearth.com)

Fig. 3. Soil sampling (block sampling).

The Nano- Magnesium and Nano-Aluminum which are used in this study were supplied by Skyspring Nanomaterials, Houston, USA. A fine white powder which their particles ranging from (10 to 50) nm in diameter. All the information was supplied by the company are shown in the Tab. 1 below.

Tab. 1 Properties of nano-magnesium oxide nano powder (as presented in the technical sheet received from Skyspring, USA) [7]

Parameter	**Value / comment**
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

Tab. 2 Properties of nano-aluminum oxide nano powder (as presented in the technical sheet received from Skyspring, USA) [7]

Parameter	**Value / comment**
Formula	Al_2O_3
Colour	White
Purity	99.9 %
Density	3.95 g/cm^3
D50	10-50 nm
Specific surface area (SSA)	$\leq$ 50 m^2/g

1.3.3 Preparation of soil-nanomaterials mixtures

Two different types of nanomaterials were used in this research, which are namely Nano-MgO with different percentages (0.5%, 0.75%, 1%, and 2%), and Nano-Al_2O_3 with percentages (0.5%,1%, and 2%), they were added to the soil samples, to study their effect on the strength, consistency limits and compressibility of the soil, in this study we have three stages to complete the experimental and theoretical works:

1. The first phase is the identification of index properties of natural soft soil (wetted loess, in our case) include: water content, sieve analysis, liquid and plastic limit, optimum water content, max. dry density, pH. Soil classification was according to the Texture classification system. Also, the compressibility characteristics, shear strength, and the microstructure of the soil by scanning electron microscopy (SEM) and X-ray diffraction (XRD).
2. The second phase is soil samples mixed with two types of nanomaterials (Nano-MgO and Nano Al_2O_3) with different percentages between (0.5% to 2%) and some samples were mixed with 2% Portland cement. The mixed soil samples were put it in a plastic bag and let for at least 48 hours for curing
3. Resulted treated and nontreated soil samples were compacted using the modified Proctor test apparatus procedure after mixing with nanomaterials. Many laboratory tests were done on the soil samples to obtain the geotechnical properties.

The amount of nanomaterial required for each specimen was determined by multiplying the nanomaterial percentage (0.5% to 2%) by the total weight of the soil sample. The reason for using a different amount of nanomaterials (i.e., Nano-MgO and Nano Al_2O_3 in this study) is to notice the effect of different particle densities and sizes of nanomaterials on the improvement of geotechnical properties of the soil samples. There are two estimated methods for mixing soil with nanomaterials, the first is to mix nanomaterials with the required amount of water and put the mixture in an ultrasonic bath for 2 hours. [8].

This method was not used in our study because the Nano MgO and Nano Al_2O_3 are insoluble in water, and it is difficult to obtain a homogeneous solution in this case. The second method was the soil samples mixed with nanomaterials and after that add the water [9]. The mixing process was manual, and the soil samples were divided into ten layers after adding the suitable amount of nano MgO for every layer alone and mixing with a horizontal cylindrical mixer. All the mixing processes were done inside an isolated glove box.

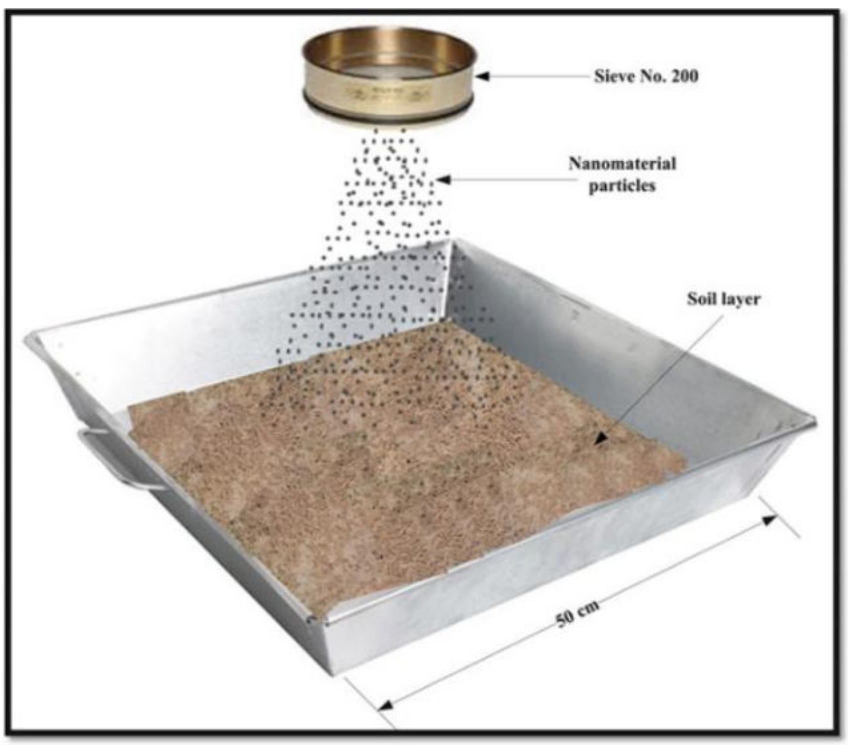


Fig. 4. Spraying of Nano MgO on the soil layer

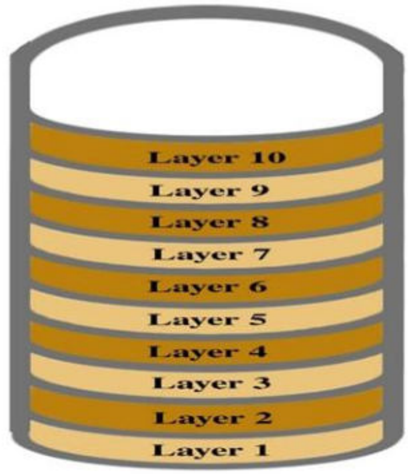


Fig. 5. Mixing all the quantity in a pot

1.4 Laboratory tests

Many laboratory tests were done on the soil samples that were obtained from the study area to get physical, mechanical, and chemical properties of the soils. Soil parameters that used in this research are calculated from the field and laboratory tests such as Scanning electron microscopy (SEM) to notice the changes of microstructure of the soil samples because of addition nano-MgO, X-Ray Diffraction (XRD) to find out the changes in the phase mineralogical reaction, pH test, Atterberg limits (The liquid limit (LL), plastic limit (PL) and plasticity index (PI=LL-PL), Oedometer test to determine the magnitude and the rate of consolidation and measuring the deformation and shear strength test (direct shear test) to get the parameter of shear strength.

1.4.1 Effect of the nanomaterials on the microstructure of the soil**.**

In order to investigate the effect of the additives on the microstructure of the soil (i.e., Nano-MgO, Nano- Al_2O_3 and cement in this study) also the purity and the size of the nanoparticles, three different tests have been done.

1.4.1.1 Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDS) or (Edax)

Scanning electron microscopy is a high-resolution electron microscope used for measurement of nanoparticles, which can observe morphology of the samples. As shown in figures 6 and 7, the nano powder has been observed and investigated at different magnification using a Scanning electron microscope [10]. A few milligrams of Nano MgO and Nano- Al_2O_3 added above carbon container and push inside in the apparatus.

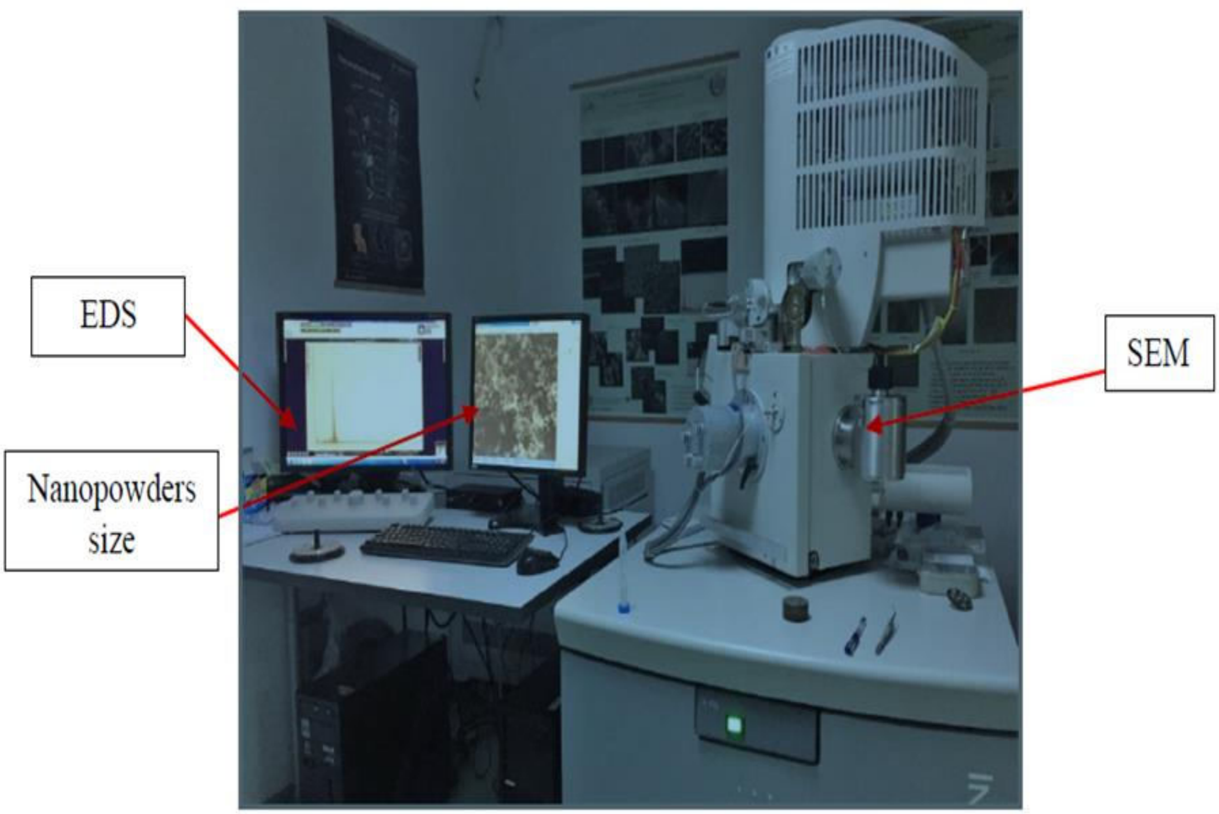


Fig. 1-6. Scanning Electron Microscopy (SEM) [11].

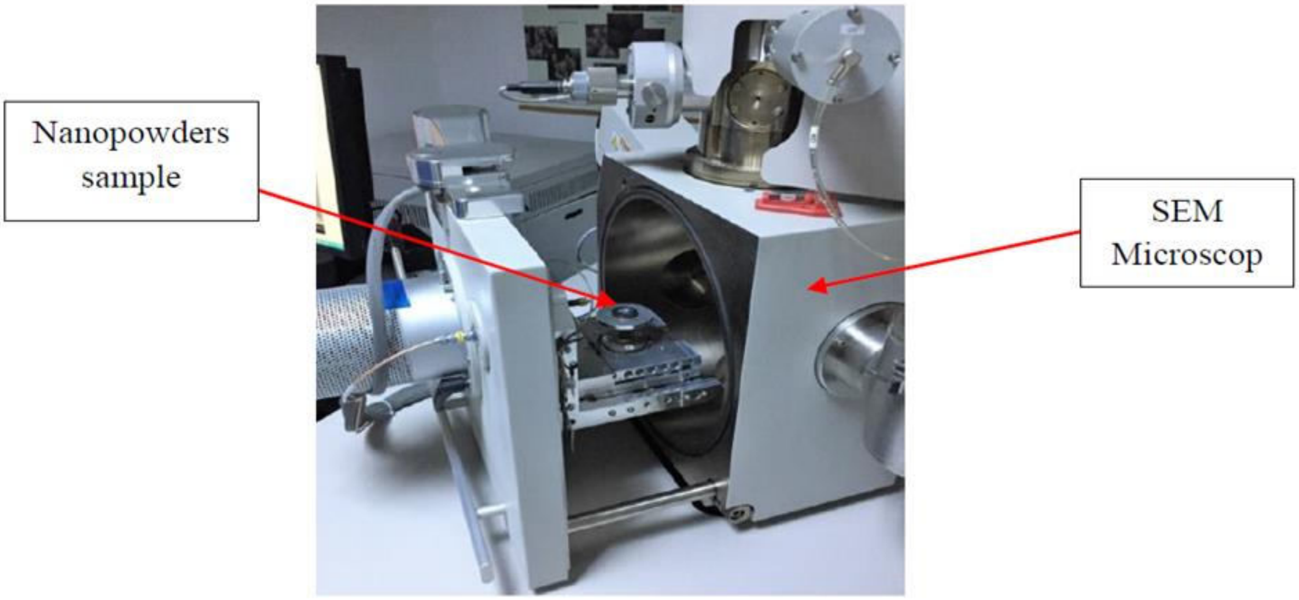


Fig. 1-7. The nano powders sample inside the SEM [11].

The Scanning electron Microscopy (SEM) images for Nano-MgO and Nano Al_2O_3 shows in figures 8 and 9.are presented at different scales of measurement (2 nm, 400nm) and (1nm, 500nm) respectively. It can be observed that all the particle size has less than 100nm.

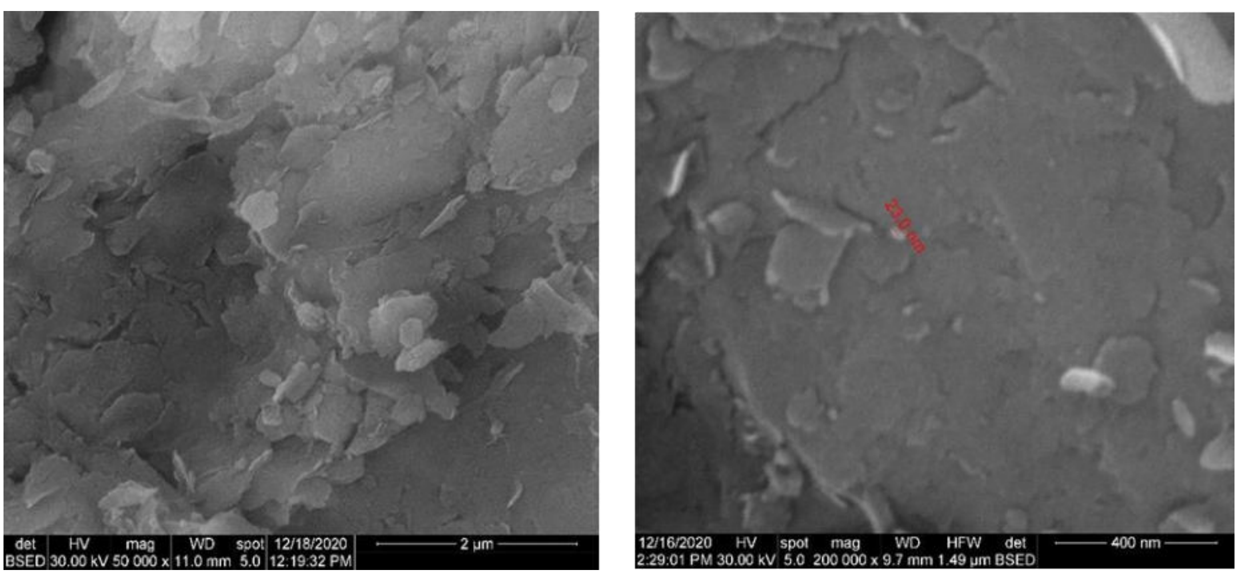


Fig. 8. SEM measurement of Nano-MgO

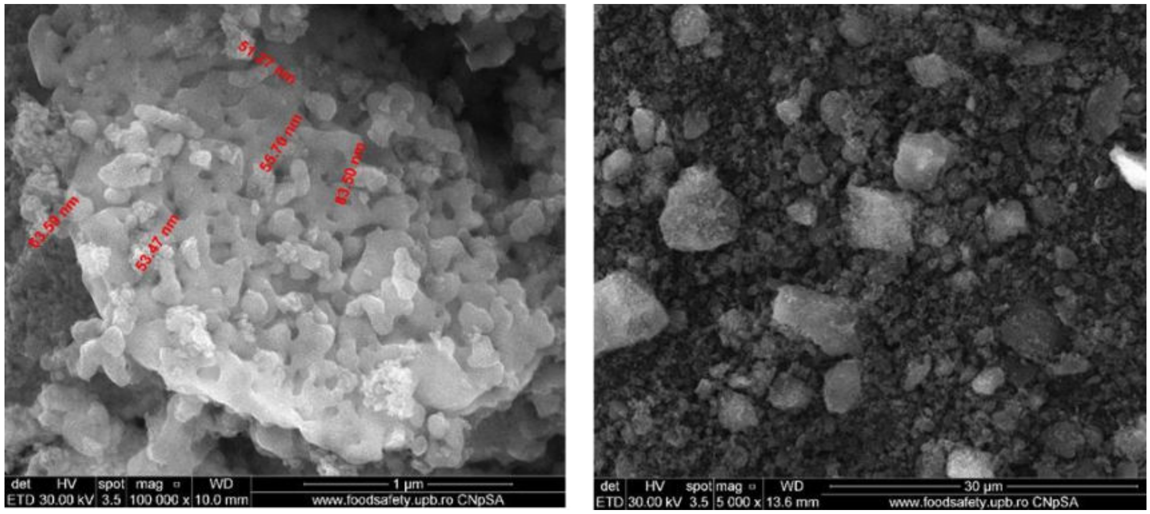


Fig. 9. SEM measurement of Nano- Al_2O_3

The changes of microstructure of the soil samples because of addition of Nano-MgO and Nano-Al_2O_3 may have an important role in improving geotechnical properties of the soil. By scanning Electron Microscopy (SEM) test, we check if there is a change in the soil structure at microscope level [9], as shown in figures (3.10, 3.11, 3.12 and 3.13.). From the results that which were obtained from SEM we could notice a small significant effect on the interaction of Nano-MgO in the soil samples. On the other hand, from the results of soil-Nano- Al_2O_3 mixtures, we can observe that a visible change in the microstructure of the samples, which occurs especially on the soil samples mixed with 2% Nano-Al_2O_3. As shown in figures 14(d), 15(d) and 16(d).

In the case of treated soil samples with 0.5% and 1% Nano-Al_2O_3, the microstructure of soil-nano-alumina mixtures indicated that the new phase formed by adding Nano Al_2O_3. It had a small interaction and consisted of some new interactions between the particles of the soil samples leading to more compact structures, as shown in figure 14 (a, b), figure15(a,b) and figure 16(a,b).

in the case of mixing cement with soil samples, the formation of the interactions between the particles can be clearly observed as shown in the figure 17.

from the point of view of morphology when the concentration of the nanoparticles increases in the samples, more uniform particles/agglomerates size distributions was observed.

By studying the influence of the type of nanomaterials added on the soil samples it was observed that the addition of the Nano-MgO leads to lower agglomerates size formations and more uniform particle/agglomerates distributions of the soil samples, comparing with adding Nano-Al_2O_3.

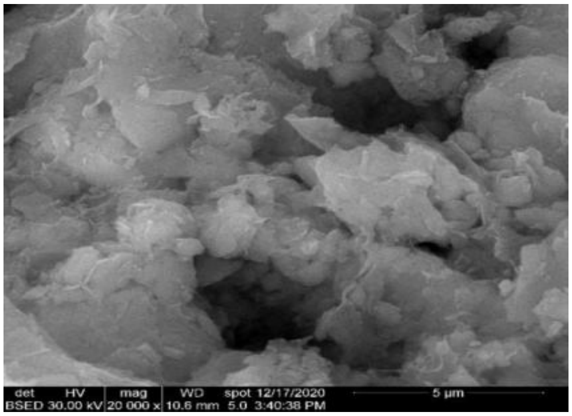
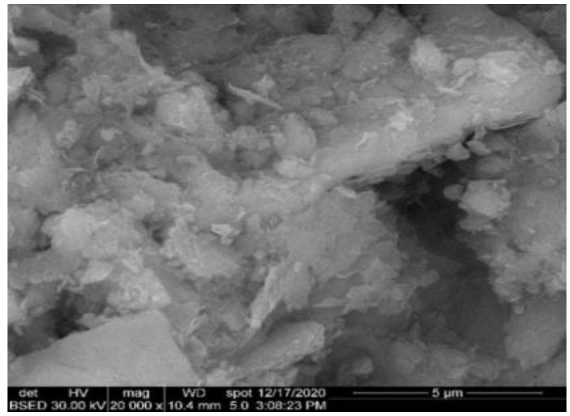
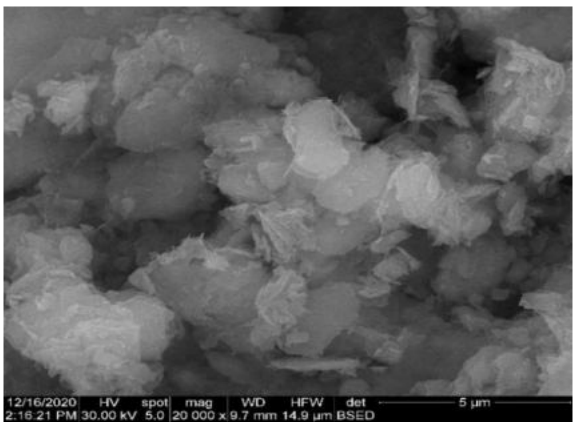
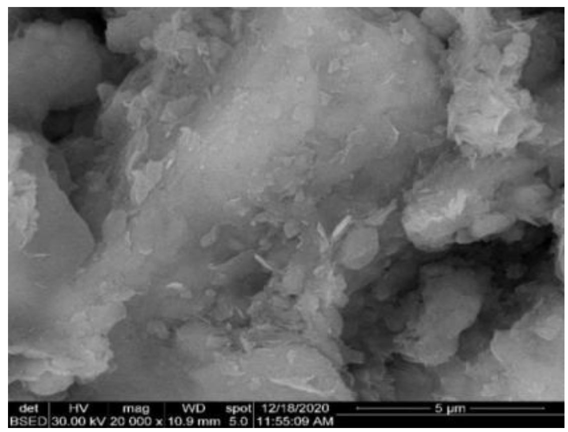
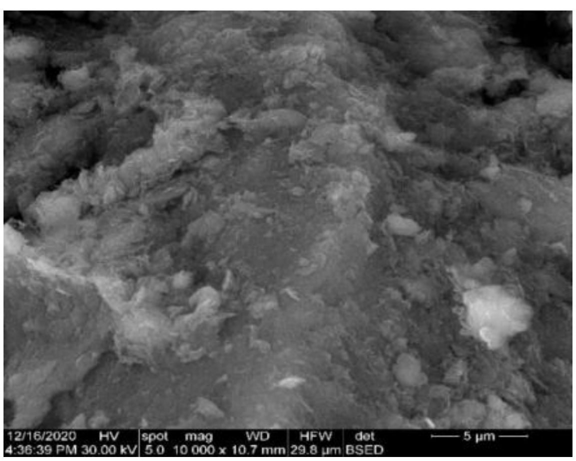
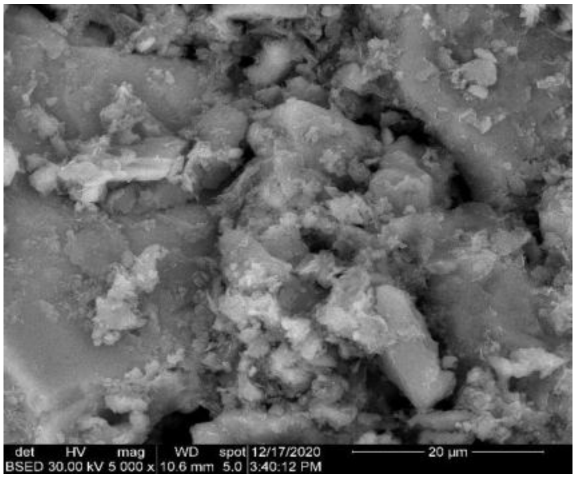
Non treated Soil	Soil treated with 0.5% Nano-MgO
 a)	 b)
 c)	 d)
Soil treated with 0.75% Nano-MgO	Soil treated with 1% Nano-MgO
 c)	
Soil treated with 2% Nano-MgO	

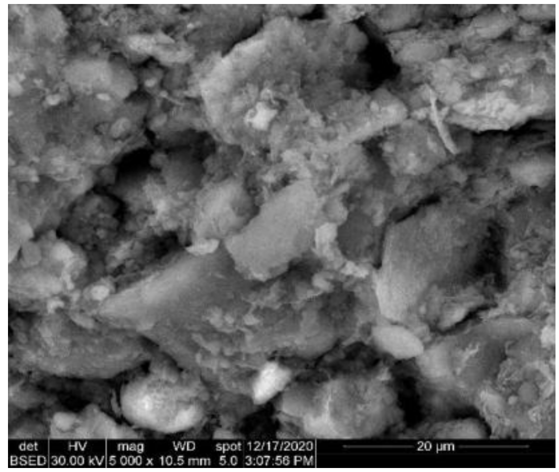
Fig. 10. SEM microscopy on soil samples with a measurement 5 μm

c

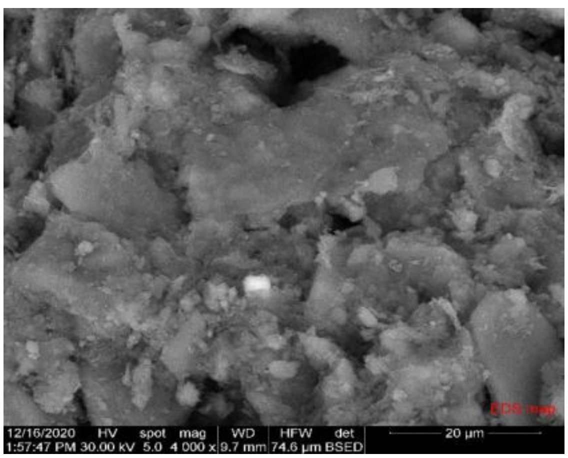
Soil treated with 0.5% Nano-MgO



a)

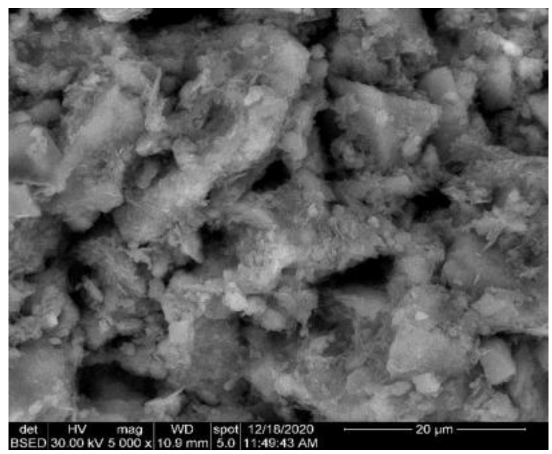


b)



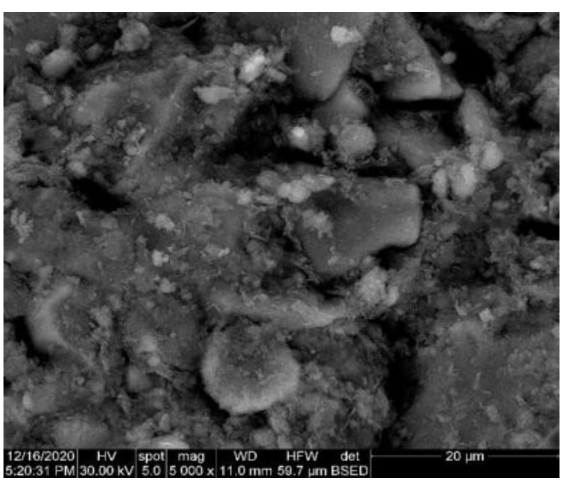
c)

Soil treated with 0.75% Nano-MgO



d)

Soil treated with 1% Nano-MgO



c)

Soil treated with 2% Nano-MgO

Fig. 11. SEM microscopy on soil samples with a measurement 20 μm

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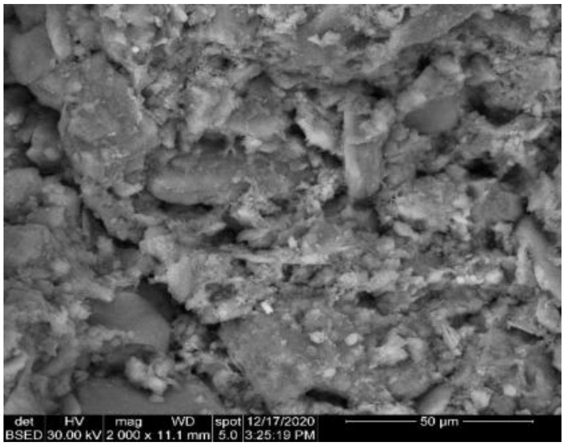
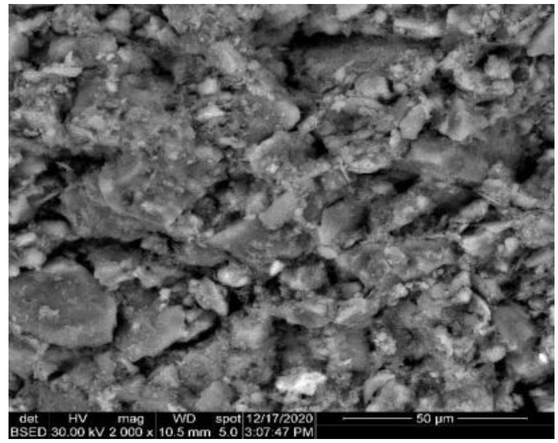
<tr><td>

a)</td><td>

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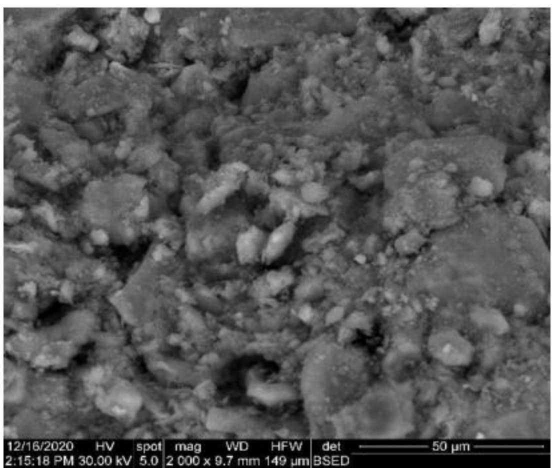
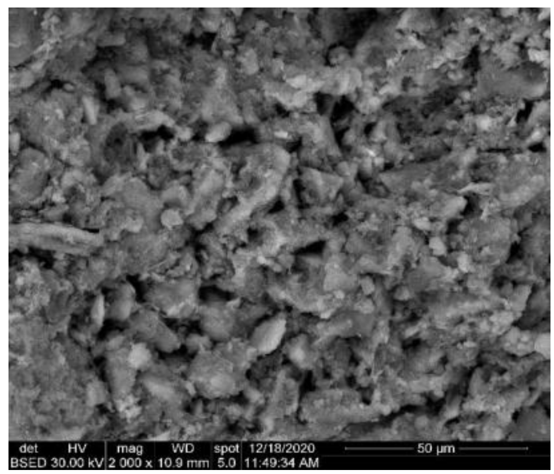
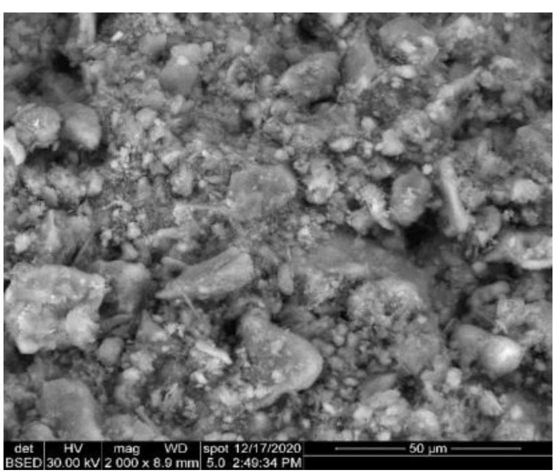
<tr><td>

c)</td><td>

d)</td></tr>
<tr><td>Soil treated with 0.75% Nano-MgO</td><td>Soil treated with 1% Nano-MgO</td></tr>
<tr><td>

c)</td><td></td></tr>
<tr><td>Soil treated with 2% Nano-MgO</td><td></td></tr>
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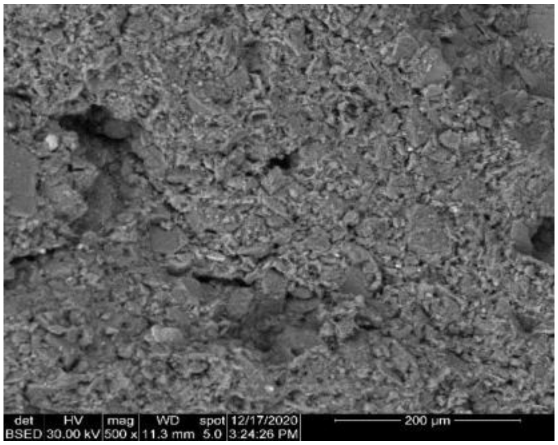
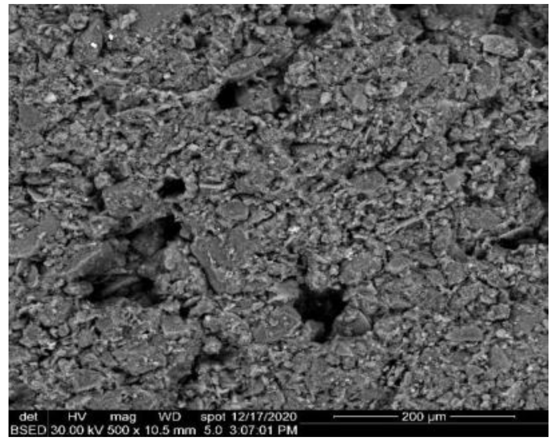
Fig. 12. SEM microscopy on soil samples with a measurement 50 μm

Non treated soiL



a)

Soil treated with 0.5% Nano-MgO



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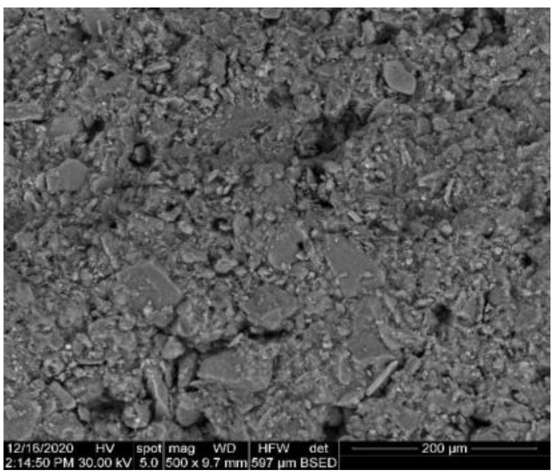
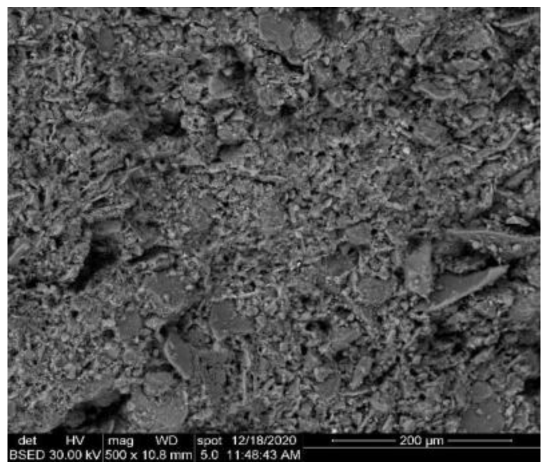


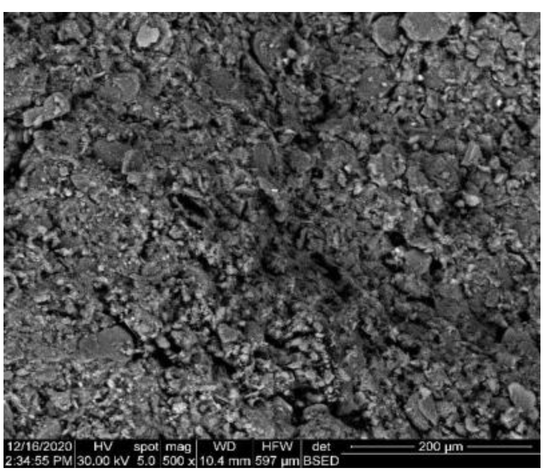
c)

Soil treated with 0.75% Nano-MgO



d)

Soil treated with 1% Nano-MgO



c)

Soil treated with 2% Nano-MgO

Fig. 13. SEM microscopy on soil samples with a measurement 200 μm

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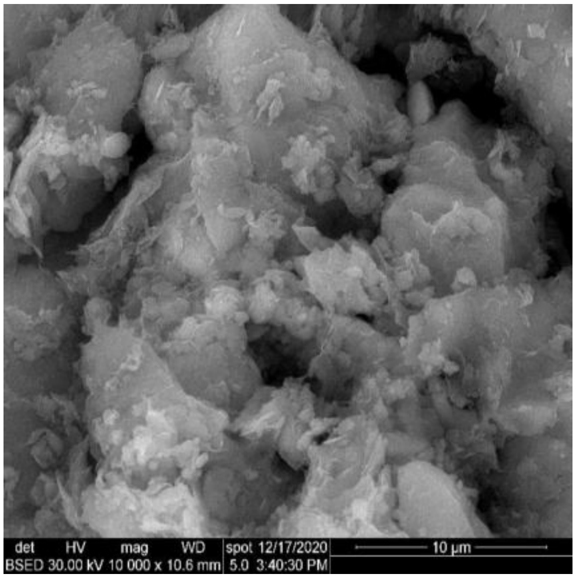
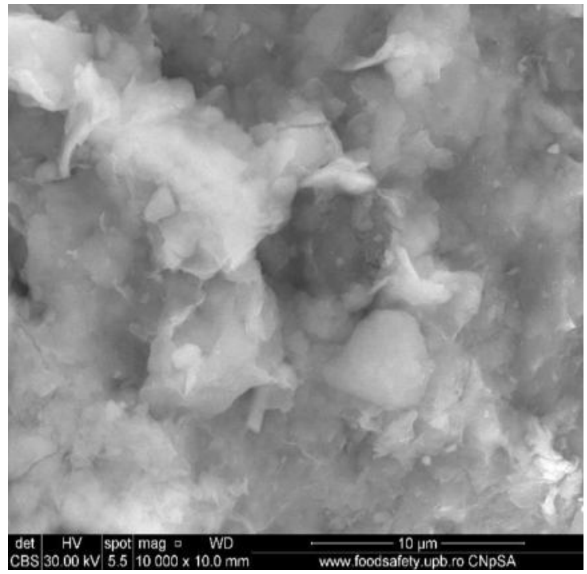
<tr><td>

a)</td><td>

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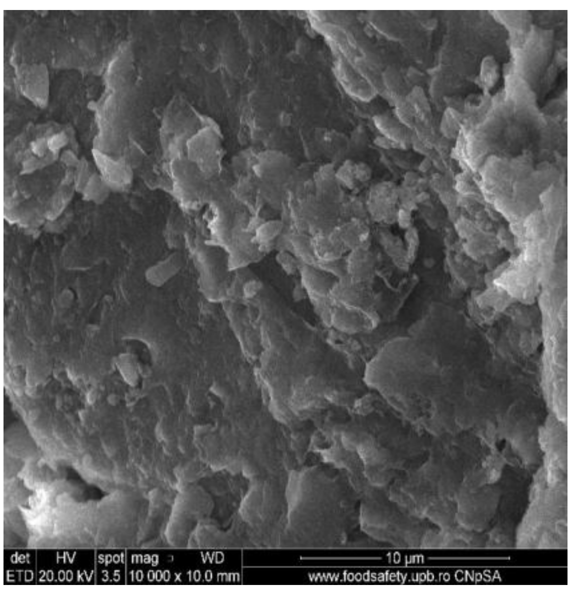
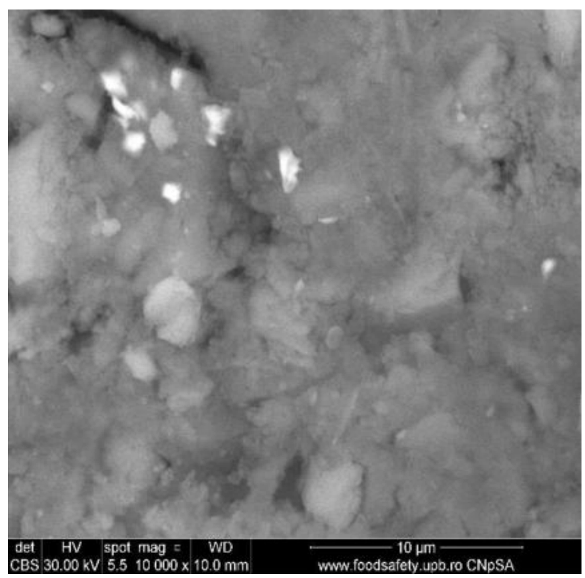
<tr><td>

c)</td><td>

d)</td></tr>
<tr><td>Loess + 1% Nano-Al_2O_3</td><td>Loess + 2% Nano-Al_2O_3</td></tr>
</table>

Fig. 14. SEM microscopy on soil samples with a measurement 10 µm

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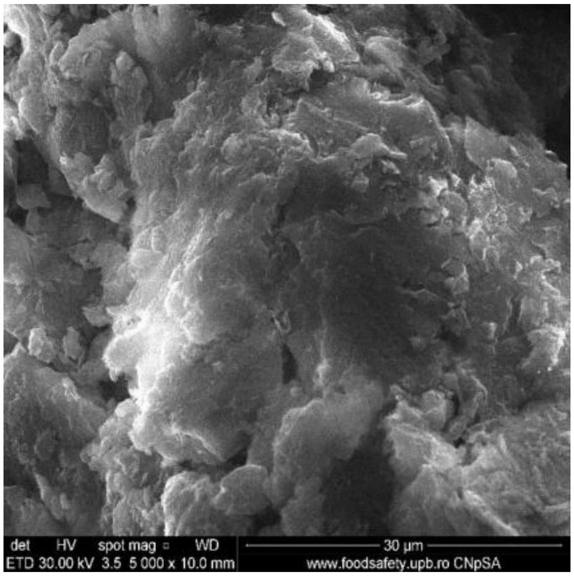
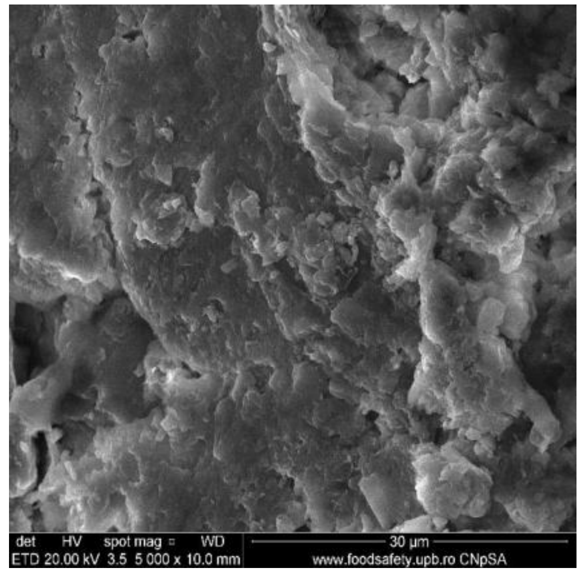
<tr><td>
</td><td>

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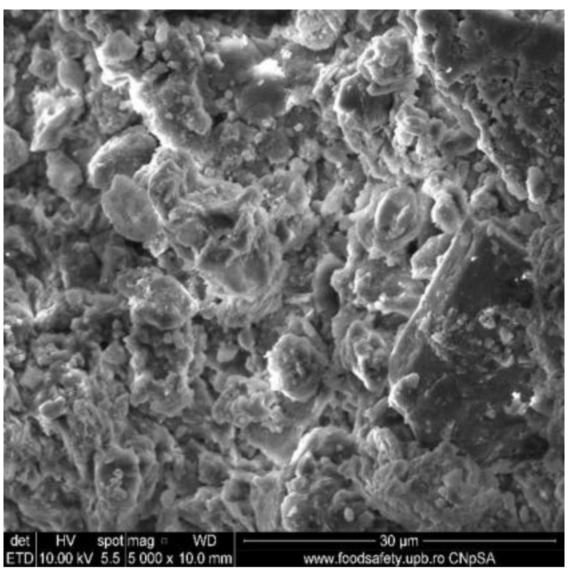
<tr><td>

c)</td><td></td></tr>
<tr><td>Loess + 2% Nano-Al_2O_3</td><td></td></tr>
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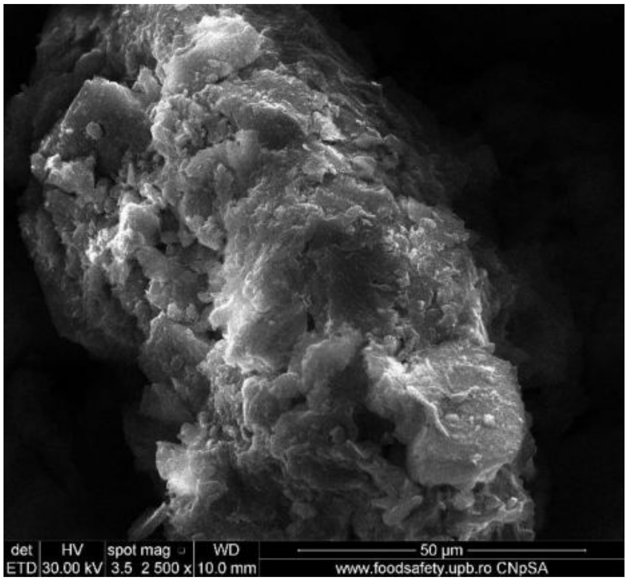
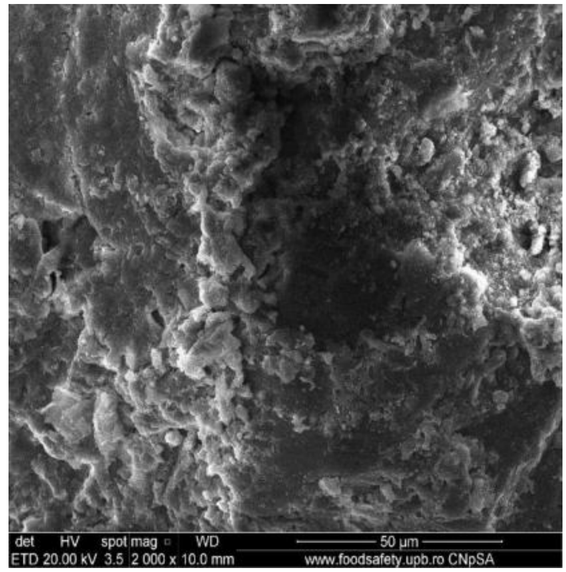
Fig. 15. SEM microscopy on soil samples with a measurement 30 μm

Loess + 0.5% Nano-Al_2O_3



Loess + 1% Nano-Al_2O_3



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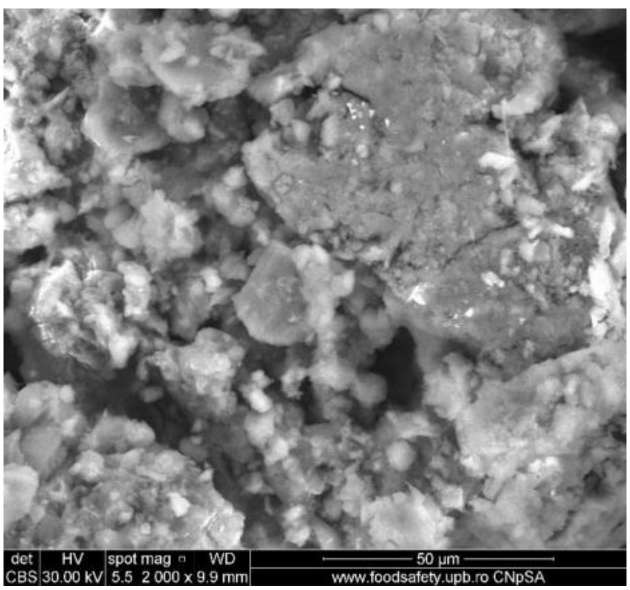


c)

Loess + 2% Nano-Al_2O_3

Fig. 16.SEM microscopy on soil samples with a measurement 50 μm

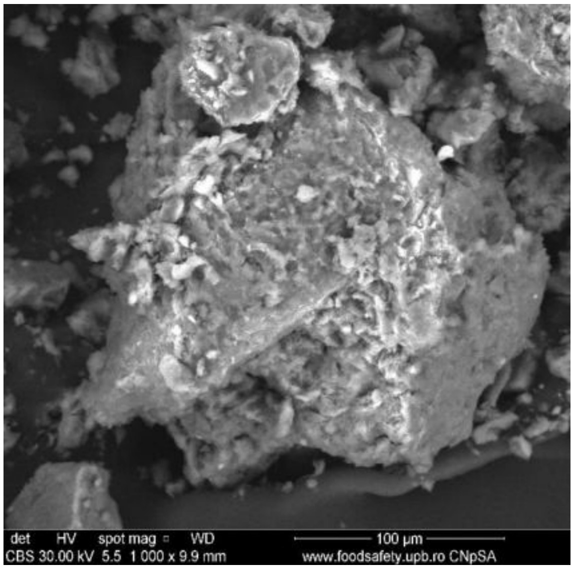
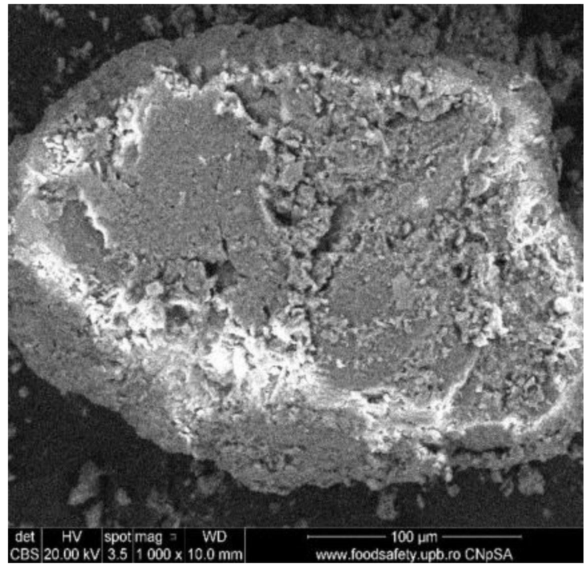
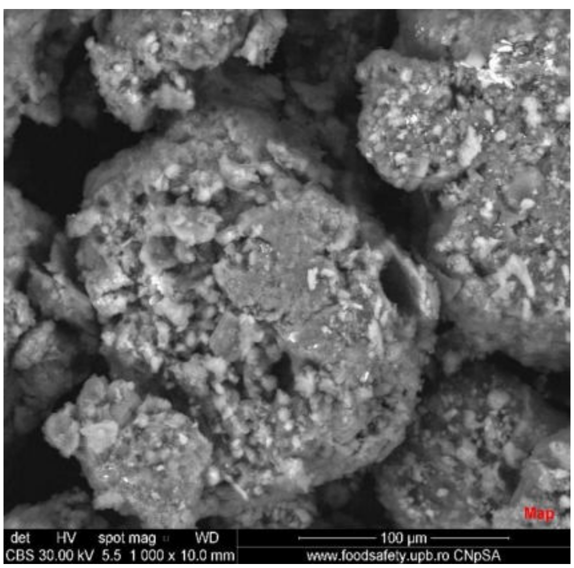
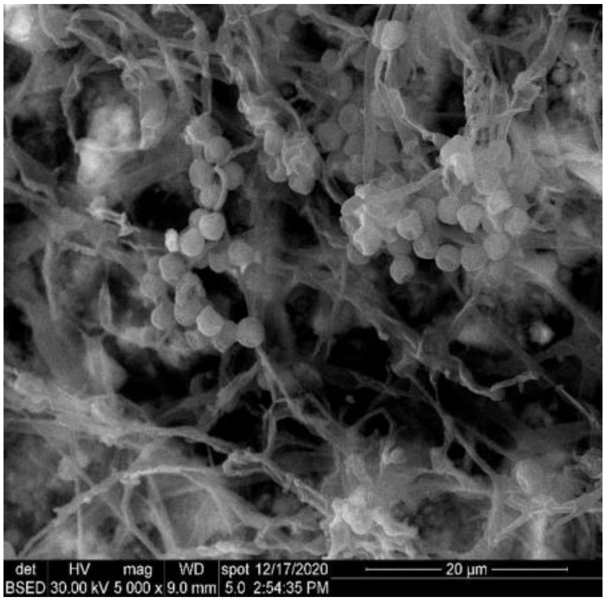
Loess + 0.5% Nano-Al_2O_3	Loess + 1% Nano-Al_2O_3
	 b)
 c)	
Loess + 2% Nano-Al_2O_3	

Fig. 17. SEM microscopy on soil samples with a measurement 30 μm



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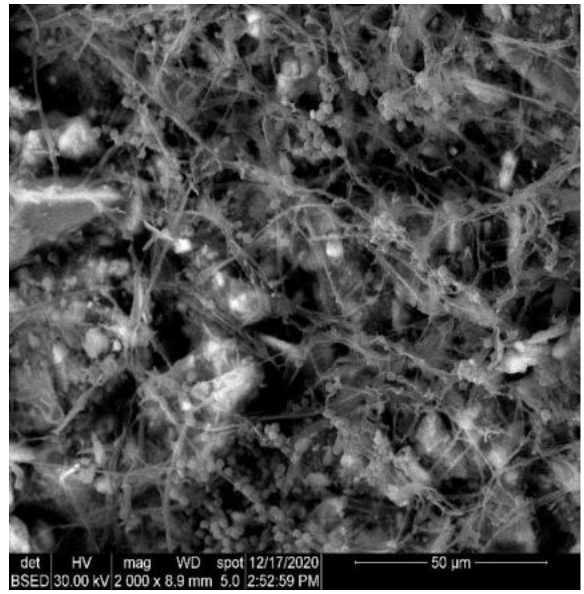
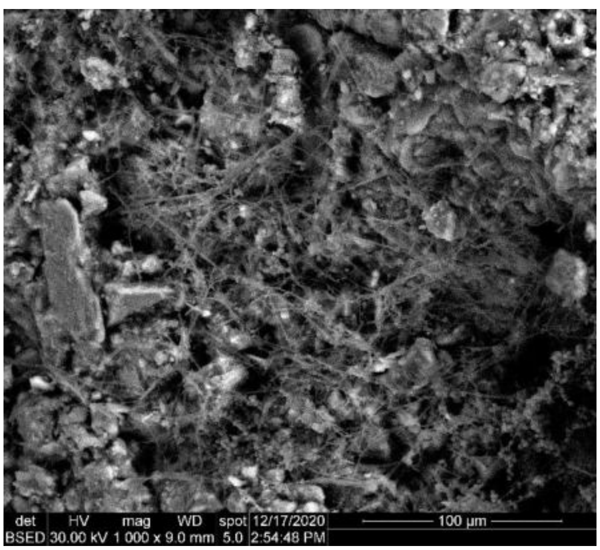


b)



c)

Fig. 18. SEM microscopy on Soil treated with 2% cement a) with a measurement of 20 µm, b) with a measurement of 50 µm, c) with a measurement of 100 µm

1.4.1.2 X-Ray Diffraction (XRD)

X-ray Diffraction is a fast analytical technique that can be used to determine the phase of a crystalline structure as well as the cell dimension., as shown in figure 19, the monochromatic X-rays and a crystalline sample are the constructive interference of X-Ray diffraction. The part of the X-Ray Diffraction consist of three basic elements which are X-Ray tube, a sample holder and X-Ray detector [12].as shown in figure 20.

Fig. 19. X-Ray Diffraction

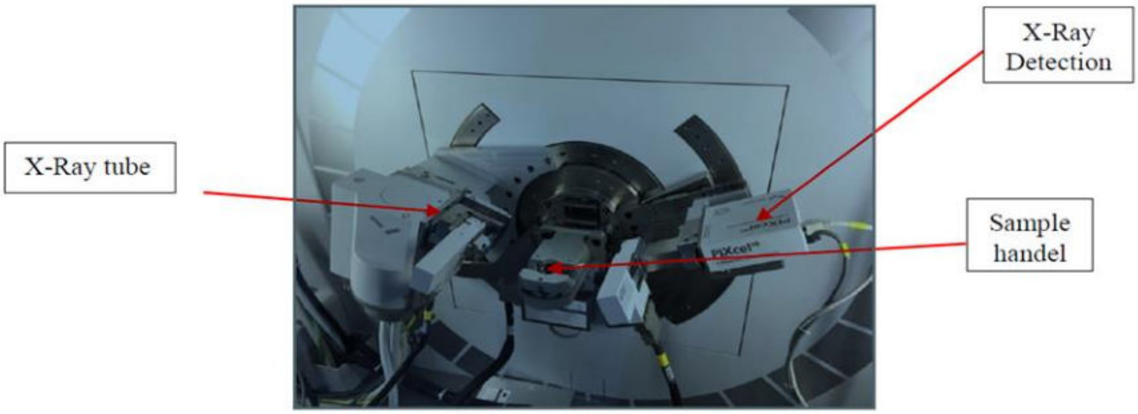


Fig. 20. X-Ray Diffraction part [12]

A strong interaction happens when the incident rays with the sample produces constructive interference, satisfy the Bragg's law [13].

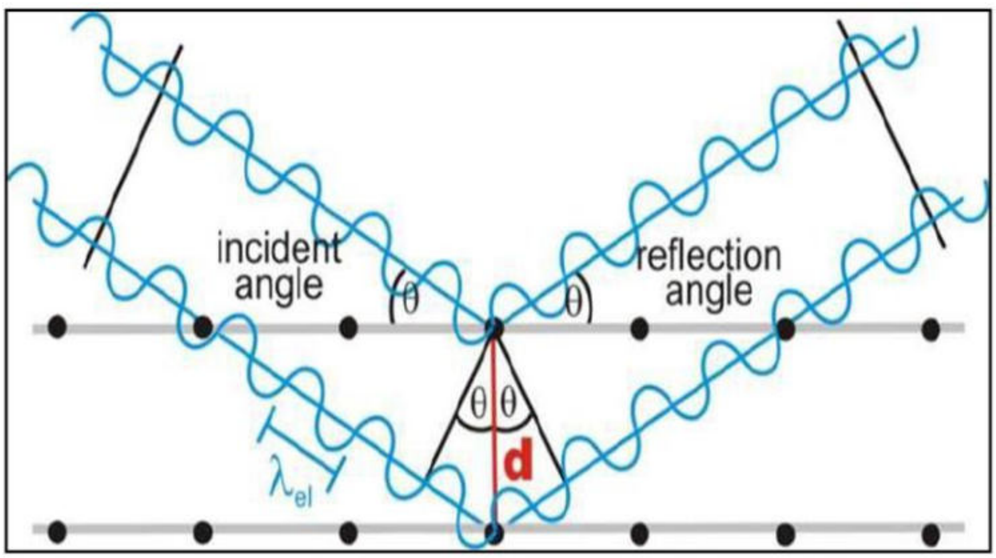


Fig. 21. X-Ray Diffraction part [14]

The detailed data which were obtained from X-ray Diffraction (XRD) pattern for soil samples treated with Nano-MgO, can be seen in figure 22, and listed in tables from 3 to 7, and soil samples treated with Nano-Al_2O_3 can be seen in figure 23 .and listed in tables from 8 to 11.

The results show that the soil samples treated with nanomaterials have a new peaks as compared with the natural soil.

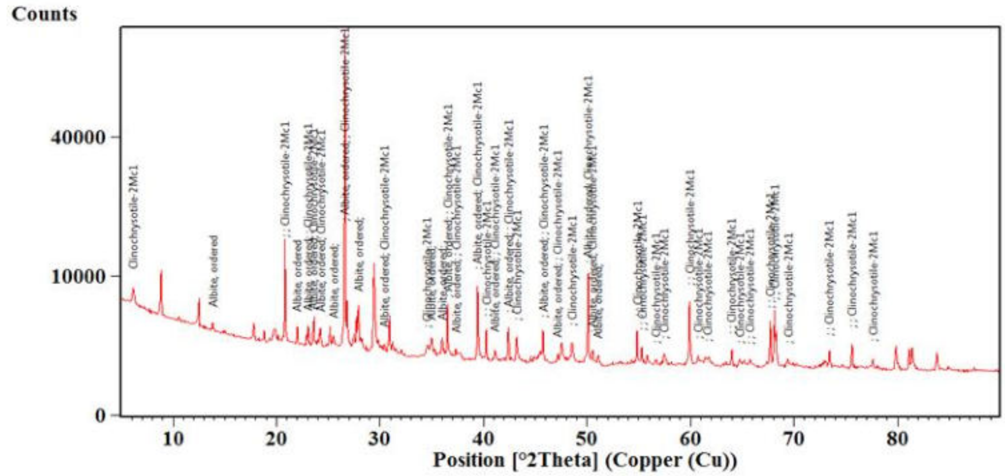


Fig. 22. The XRD pattern of the non-treated soil

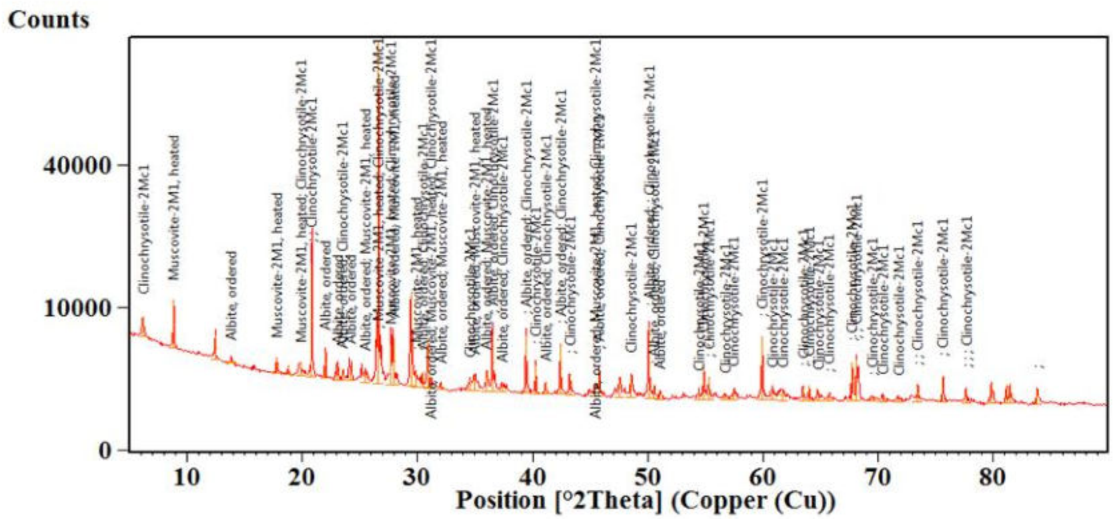


Fig. 23. The XRD pattern of the Soil mixed with 0.5% Nano-MgO

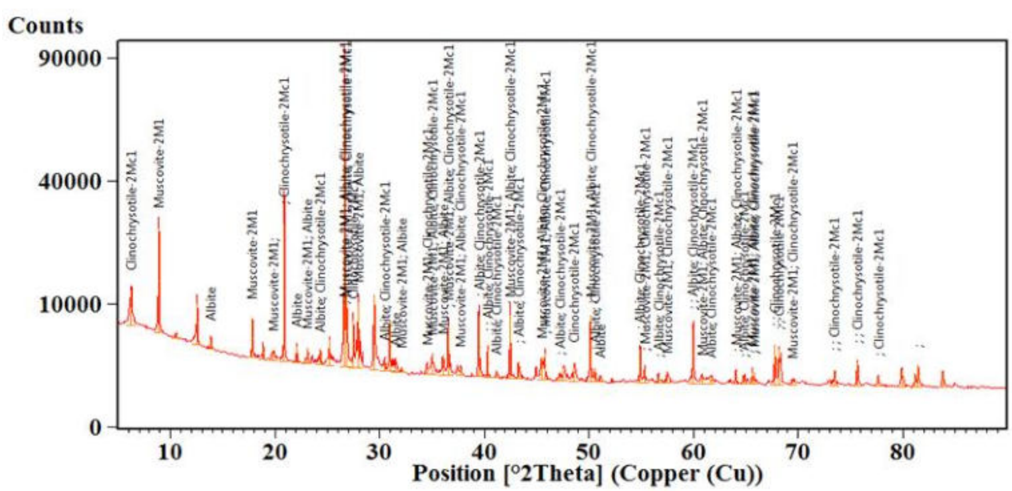


Fig. 24. The XRD pattern of the Soil mixed with 0.75% Nano-MgO

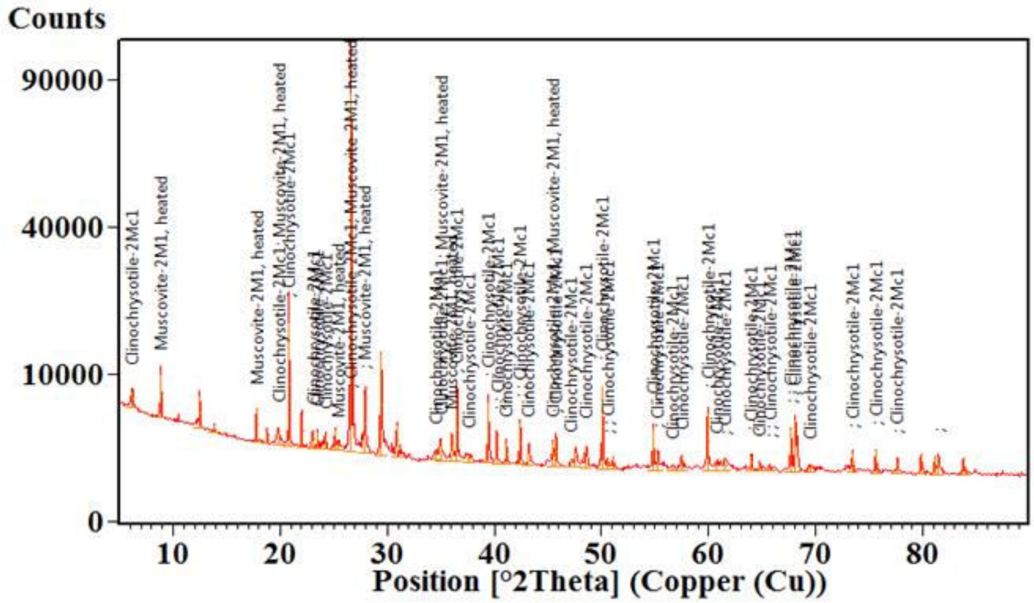


Fig. 25. The XRD pattern of the Soil mixed with 1% Nano-MgO

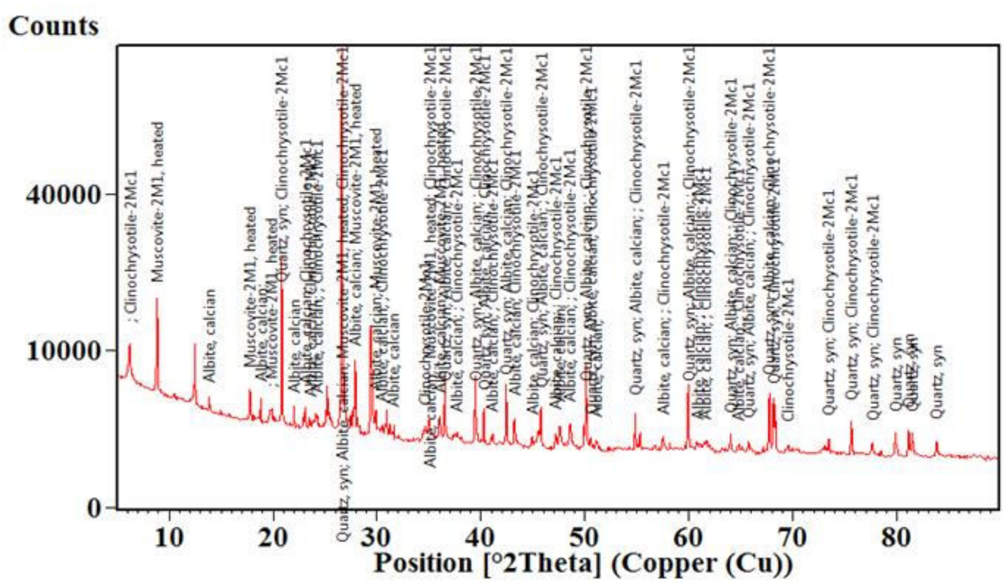


Fig. 26. The XRD pattern of the Soil mixed with 2% Nano-MgO

Tab. 3 Analysis of the XRD pattern for the natural soil.

Non-treated Soil	Peak	Formula from diffractogram
	2	Clinochrysotile-2Mc1
	8	Muscovite-2M1, heated
	12	Albite, calcian
	17	Muscovite-2M1, heated
	18	Albite, calcian
	19	Muscovite-2M1, heated
	21	Quartz, syn, Clinochrysotile-2Mc1
	22	Albite, calcian
	23	Albite, calcian, Clinochrysotile-2Mc1
	24	Albite, calcian, Clinochrysotile-2Mc1
	27	Quartz, syn, Albite, calcian, Muscovite-2M, heated, Clinochrysotile-2Mc1
	28	Albite, calcian, Muscovite-2M1, heated
	29	Albite, calcian, Muscovite-2M1, heated
	30	Albite, calcian, Muscovite-2M1, heated
	31	Albite, calcian, Clinochrysotile-2Mc1
	32	Albite, calcian
	35	Clinochrysotile-2Mc1
	37	Albite, calcian, Clinochrysotile-2Mc1
	39	Quartz, syn, Albite, calcian, Clinochrysotile-2Mc1
	40	Quartz, syn, Albite, calcian, Clinochrysotile-2Mc1
	41	Albite, calcian, Clinochrysotile-2Mc1
	42	Quartz, syn, Albite, calcian, Clinochrysotile-2Mc1
	43	Quartz, syn, Albite, calcian, Clinochrysotile-2Mc1
	45	Albite, calcian, Clinochrysotile-2Mc1
	46	Quartz, syn, Albite, calcian, Clinochrysotile-2Mc1
	47	Albite, calcian, Clinochrysotile-2Mc1
	49	Albite, calcian, Clinochrysotile-2Mc1
	50	Quartz, syn, Albite, calcian, Clinochrysotile-2Mc1
	55	Quartz, syn, Albite, calcian, Clinochrysotile-2Mc1
	58	Albite, calcian, Clinochrysotile-2Mc1
	60	Quartz, syn, Albite, calcian, Clinochrysotile-2Mc1
	61	Albite, calcian, Clinochrysotile-2Mc1
	62	Albite, calcian, Clinochrysotile-2Mc1
	64	Quartz, syn,Albite, calcian, Clinochrysotile-2Mc1
	67	Quartz, syn,Albite, calcian, Clinochrysotile-2Mc1
	69	Quartz, syn,Albite, calcian, Clinochrysotile-2Mc1
	70	Clinochrysotile-2Mc1
	74	Quartz, syn, Clinochrysotile-2Mc1
	76	Quartz, syn, Clinochrysotile-2Mc1
	78	Quartz, syn, Clinochrysotile-2Mc1
	80	Quartz, syn
	82	Quartz, syn
	84	Quartz, syn

Tab. 4 Analysis of the XRD pattern for Soil treated with 0.5% Nano-MgO

Soil samples +0.5% Nano-MgO	Peak	Formula from difractogram
	2	Clinochrysotile-2Mc1
	8	Muscovite-2M1, heated
	14	Albite, ordered
	17	Muscovite-2M1, heated
	19	Muscovite-2M1, heated, Clinochrysotile-2Mc1
	21	Clinochrysotile-2Mc1
	22	Albite, ordered
	23	Albite, ordered
	24	Albite , ordered, Clinochrysotile-2Mc1
	25	Albite, ordered, Muscovite-2M1, heated
	26	Muscovite-2M1, heated, Clinochrysotile-2Mc1
	28	Muscovite-2M1, heated, Clinochrysotile-2Mc1
	29	Muscovite-2M1, heated
	31	Albite, ordered, Muscovite-2M1, heated, Clinochrysotile-2Mc1
	35	Clinochrysotile-2Mc1
	37	Albite, ordered, Muscovite-2M1, heated
	39	Albite, ordered, Clinochrysotile-2Mc1
	40	Clinochrysotile-2Mc1
	42	Albite, ordered, Clinochrysotile-2Mc1
	46	Albite, ordered, Muscovite-2M1, heated, Clinochrysotile-2Mc1
	49	Clinochrysotile-2Mc1
	50	Albite, ordered, Clinochrysotile-2Mc1
	55	Clinochrysotile-2Mc1
	60	Clinochrysotile-2Mc1
	61	Clinochrysotile-2Mc1
	62	Clinochrysotile-2Mc1
	64	Clinochrysotile-2Mc1
	65	Clinochrysotile-2Mc1
	66	Clinochrysotile-2Mc1
	68	Clinochrysotile-2Mc1
	69	Clinochrysotile-2Mc1
	70	Clinochrysotile-2Mc1
	74	Clinochrysotile-2Mc1
	76	Clinochrysotile-2Mc1
	80	Clinochrysotile-2Mc1

Tab. 5 Analysis of the XRD pattern for Soil treated with 0.75% Nano-MgO

Soil samples +0.75% Nano-MgO	Peak	Formula from diffractogram
	2	Clinochrysotile-2Mc1
	8	Muscovite-2M1
	14	Albite
	18	Muscovite-2M1
	20	Muscovite-2M1
	21	Albite
	23	Muscovite-2M1, Albite
	24	Albite, Clinochrysotile-2Mc1
	27	Muscovite-2M1, Albite, Clinochrysotile-2Mc1
	28	Clinochrysotile-2Mc1
	29	Muscovite-2M1
	30	Albite, Clinochrysotile-2Mc1
	31	Albite
	33	Muscovite-2M1, Albite
	35	Muscovite-2M1, Clinochrysotile-2Mc1
	37	Muscovite-2M1, Albite, Clinochrysotile-2Mc1
	38	Muscovite-2M1, Albite, Clinochrysotile-2Mc1
	39	Albite, Clinochrysotile-2Mc1
	40	Albite, Clinochrysotile-2Mc1
	43	Muscovite-2M1, Albite, Clinochrysotile-2Mc1
	44	Albite, Clinochrysotile-2Mc1
	46	Muscovite-2M1, Albite, Clinochrysotile-2Mc1
	48	Albite, Clinochrysotile-2Mc1
	49	Clinochrysotile-2Mc1
	50	Muscovite-2M1, Albite, Clinochrysotile-2Mc1
	55	Albite, Clinochrysotile-2Mc1
	57	Albite, Clinochrysotile-2Mc1
	58	Muscovite-2M1, Clinochrysotile-2Mc1
	60	Albite, Clinochrysotile-2Mc1
	61	Muscovite-2M1, Albite, Clinochrysotile-2Mc1
	62	Albite, Clinochrysotile-2Mc1
	67	Muscovite-2M1, Albite, Clinochrysotile-2Mc1
	68	Muscovite-2M1, Clinochrysotile-2Mc1
	70	Clinochrysotile-2Mc1
	73	Clinochrysotile-2Mc1
	75	Clinochrysotile-2Mc1
	78	Clinochrysotile-2Mc1

Tab. 6 Analysis of the XRD pattern for Soil treated with 1% Nano-MgO

Soil samples +1% Nano-MgO	Peak	Formula from diffractogram
	2	Clinochrysotile-2Mc1
	8	Muscovite-2M1, heated
	18	Muscovite-2M1, heated
	20	Clinochrysotile-2Mc1Muscovite-2M1, heated
	21	Clinochrysotile-2Mc1
	23	Clinochrysotile-2Mc1
	24	Muscovite-2M1, heated
	27	Clinochrysotile-2Mc1, Muscovite-2M1, heated
	28	Muscovite-2M1, heated
	29	Muscovite-2M1
	35	Clinochrysotile-2Mc1
	36	Clinochrysotile-2Mc1, Muscovite-2M1, heated
	37	Clinochrysotile-2Mc1
	39	Clinochrysotile-2Mc1
	40	Clinochrysotile-2Mc1
	41	Clinochrysotile-2Mc1
	42	Clinochrysotile-2Mc1
	43	Clinochrysotile-2Mc1
	45	Clinochrysotile-2Mc1, Muscovite-2M1, heated
	48	Clinochrysotile-2Mc1
	49	Clinochrysotile-2Mc1
	50	Clinochrysotile-2Mc1
	55	Clinochrysotile-2Mc1
	57	Clinochrysotile-2Mc1
	58	Clinochrysotile-2Mc1
	60	Clinochrysotile-2Mc1
	64	Clinochrysotile-2Mc1
	68	Clinochrysotile-2Mc1
	70	Clinochrysotile-2Mc1
	73	Clinochrysotile-2Mc1
	76	Clinochrysotile-2Mc1
	78	Clinochrysotile-2Mc1

Tab. 7 Analysis of the XRD pattern for Soil treated with 2% Nano-MgO

Soil samples +2% Nano-MgO	Peak	Formula from diffractogram
	2	Clinochrysotile-2Mc1
	8	Muscovite-2M1, heated
	14	Albite, calcian
	18	Muscovite-2M1, heated
	19	Albite, calcian
	20	Muscovite-2M1, heated
	21	Quartz, syn, Clinochrysotile-2Mc1
	22	Albite, calcian
	23	Albite, calcian, Clinochrysotile-2Mc1
	24	Albite, calcian, Clinochrysotile-2Mc1
	26	Quartz, syn, Albite, calcian, Muscovite-2M1, heated, Clinochrysotile-2Mc1
	28	Albite, calcian, Muscovite-2M1, heated
	30	Albite, calcian, Muscovite-2M1, heated
	31	Albite, calcian, Clinochrysotile-2Mc1
	32	Albite, calcian
	34	Clinochrysotile-2Mc1
	35	Albite, calcian, Muscovite-2M1, heated, Clinochrysotile-2Mc1
	37	Albite, calcian, Clinochrysotile-2Mc1, Muscovite-2M1, heated
	38	Albite, calcian, Clinochrysotile-2Mc1
	39	Quartz, syn, Albite, calcian, Clinochrysotile-2Mc1
	40	Quartz, syn, Albite, calcian, Clinochrysotile-2Mc1
	41	Albite, calcian, Clinochrysotile-2Mc1
	43	Quartz, syn, Albite, calcian, Clinochrysotile-2Mc1
	44	Albite, calcian, Clinochrysotile-2Mc1
	46	Albite, calcian, Clinochrysotile-2Mc1

	48	Albite, calcian, Clinochrysotile-2Mc1
	49	Albite, calcian, Clinochrysotile-2Mc1
	50	Quartz, syn, Albite, calcian, Clinochrysotile-2Mc1
	55	Quartz, syn, Albite, calcian, Clinochrysotile-2Mc1
	58	Albite, calcian, Clinochrysotile-2Mc1
	60	Quartz, syn, Albite, calcian, Clinochrysotile-2Mc1
	61	Albite, calcian, Clinochrysotile-2Mc1
	62	Albite, calcian, Clinochrysotile-2Mc1
	64	Quartz, syn, Albite, calcian, Clinochrysotile-2Mc1
	65	Albite, calcian, Clinochrysotile-2Mc1
	66	Quartz, syn, Albite, calcian, Clinochrysotile-2Mc1
	68	Quartz, syn, Albite, calcian, Clinochrysotile-2Mc1
	69	Quartz, syn, Clinochrysotile-2Mc1
	70	Clinochrysotile-2Mc1
	74	Quartz, syn, Clinochrysotile-2Mc1
	76	Quartz, syn, Clinochrysotile-2Mc1
	78	Quartz, syn, Clinochrysotile-2Mc1
	80	Clinochrysotile-2Mc1
	81	Clinochrysotile-2Mc1
	83	Clinochrysotile-2Mc1

The untreated soil and the soil treated with (0.5%, 0.75%) Nano-MgO as shown in tables 3.3, 3.4 and 3.5 contain three crystal phases, Clinochrysotile-2Mc1is a fibrous silicate mineral has a chemical formula $Mg_3(Si_2O_5)(OH)_4$ and it has some of the physical properties that make it desirable for using in the building materials, Muscovite-2M1 is a hydrated Phyllosilicate mineral of aluminum with formula $KAl_2(AlSi_3O_{10})(F,OH)_2$ and Albite is a plagioclase feldspar mineral with formula $NaAlSi_3O_8$, It is found usually in felsic rocks [15]. In the case of soil treated with 1%

Nano-MgO, the samples consist of two crystal phases, the first is Clinochrysotile-2Mc1and Muscovite-2M1. On other hand the soil samples which were treated with 2% Nano-MgO contain from three crystal phases, as mentioned in the case of the soil treated with (0.5% and 0.75%) Nano-MgO.

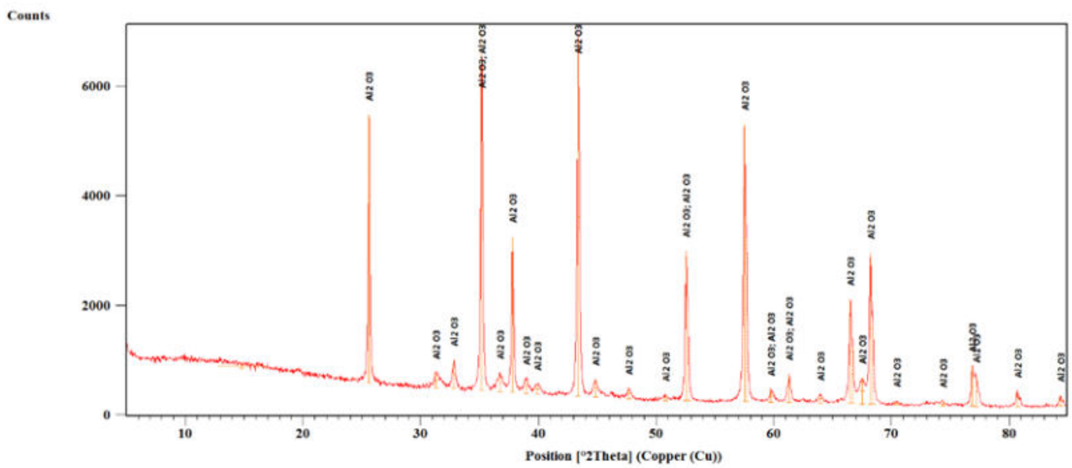


Fig. 27. The XRD pattern of the Nano-Al_2O_3

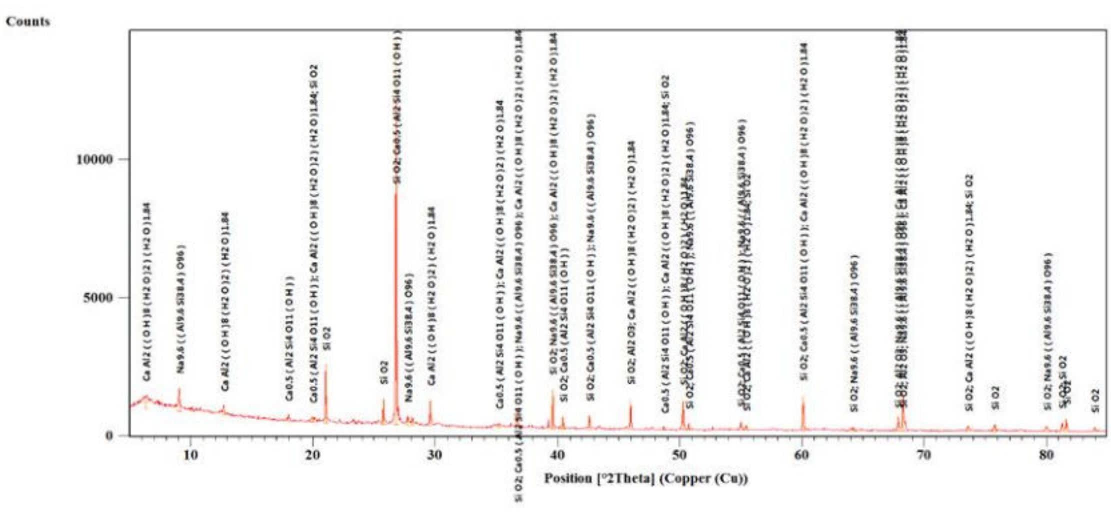


Fig. 28. The XRD pattern of the Soil treated with 0.5% Nano-Al_2O_3

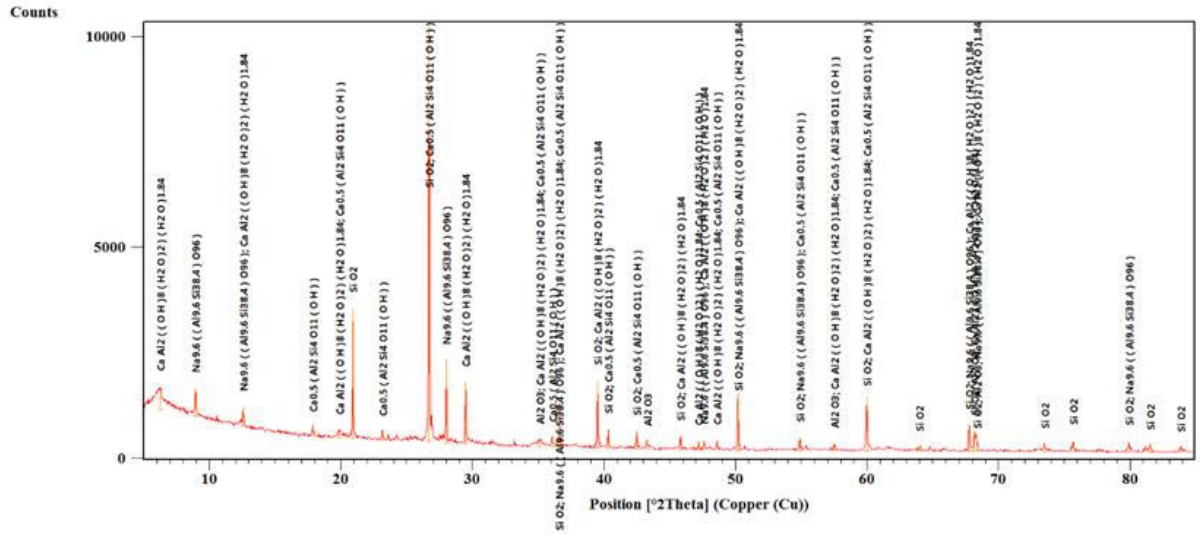


Fig. 29. The XRD pattern of the Soil treated with 1% Nano-Al_2O_3

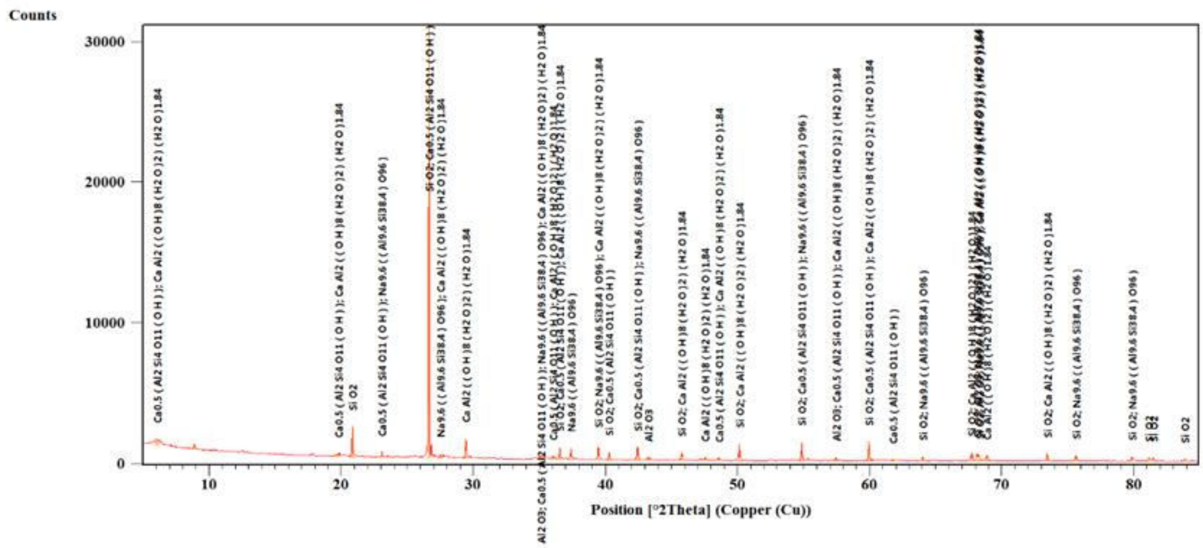


Fig. 30. The XRD pattern of the Soil treated with 2% Nano-Al_2O_3

Tab. 8 Analysis of the XRD pattern of the Nano-Al_2O_3

Nano-Al_2O_3	Peak	Formula from diffractogram
	25	Al_2O_3
	31	Al_2O_3
	33	Al_2O_3
	35	Al_2O_3, Al_2O_3
	36	Al_2O_3
	38	Al_2O_3
	39	Al_2O_3
	40	Al_2O_3
	43	Al_2O_3
	45	Al_2O_3
	48	Al_2O_3
	51	Al_2O_3
	53	Al_2O_3, Al_2O_3
	58	Al_2O_3
	60	Al_2O_3, Al_2O_3
	62	Al_2O_3, Al_2O_3
	64	Al_2O_3
	67	Al_2O_3
	68	Al_2O_3
	69	Al_2O_3
	70	Al_2O_3
	74	Al_2O_3
	77	Al_2O_3
	81	Al_2O_3
	84	Al_2O_3

Tab. 9 Analysis of the XRD pattern for Soil treated with 0.5% Nano-Al_2O_3

Soil samples +0.5 %Nano-Al_2O_3	Peak	Formula from diffractogram
	4	Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	8	Na9.6 ((Al9.6 Si38.4) O96)
	14	Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	18	Ca0.5(Al2 Si4 O11 (OH))
	20	Ca0.5(Al2 Si4 O11 (OH)), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84, Si O2
	21	Si O2
	26	Si O2
	27	Si O2, Ca0.5(Al2 Si4 O11 (OH))
	28	Na9.6 ((Al9.6 Si38.4) O96)
	30	Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	35	Ca0.5(Al2 Si4 O11 (OH)), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	37	Si O2, Ca0.5(Al2 Si4 O11 (OH)), Na9.6 ((Al9.6 Si38.4) O96), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	39	Si O2, Na9.6 ((Al9.6 Si38.4) O96), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	41	Si O2, Ca0.5(Al2 Si4 O11 (OH))
	43	Si O2, Ca0.5(Al2 Si4 O11 (OH)), Na9.6 ((Al9.6 Si38.4) O96)
	46	Si O2, Al_2O_3, Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	49	Ca0.5(Al2 Si4 O11 (OH)), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84, Si O2
	50	Si O2, Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	51	Si O2, Ca0.5(Al2 Si4 O11 (OH)), Na9.6 ((Al9.6 Si38.4) O96)
	55	Si O2, Ca0.5(Al2 Si4 O11 (OH)), Na9.6 ((Al9.6 Si38.4) O96)
	56	Si O2, Ca Al2((OH)8 (H_2O)2) (H_2O)1.84, Si O2
	60	Si O2, Ca0.5(Al2 Si4 O11 (OH)), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	64	Si O2, Na9.6 ((Al9.6 Si38.4) O96)
	68	Si O2, $Al_2O_{3,}$ Na9.6 ((Al9.6 Si38.4) O96), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	69	Si O2, $Al_2O_{3,}$ Na9.6 ((Al9.6 Si38.4) O96), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	74	Si O2, Ca Al2((OH)8 (H_2O)2) (H_2O)1.84, Si O2
	76	Si O2
	80	Si O2, Na9.6 ((Al9.6 Si38.4) O96)
	82	Si O2 Si O2
	85	Si O2

Tab. 10 Analysis of the XRD pattern for Soil treated with 1% Nano-Al_2O_3

Soil samples +1% Nano-Al_2O_3	Peak	Formula from diffractogram
	4	Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	8	Na9.6 ((Al9.6 Si38.4) O96)
	14	Na9.6 ((Al9.6 Si38.4) O96), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	18	Ca0.5(Al2 Si4 O11 (OH))
	20	Ca Al2((OH)8 (H_2O)2) (H_2O)1.84, Ca0.5(Al2 Si4 O11 (OH))
	21	Si O2
	23	Ca0.5(Al2 Si4 O11 (OH))
	27	Si O2, Ca0.5(Al2 Si4 O11 (OH))
	28	Na9.6 ((Al9.6 Si38.4) O96)
	30	Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	35	Al_2O_3, Ca Al2((OH)8 (H_2O)2) (H_2O)1.84, Ca0.5(Al2 Si4 O11 (OH))
	37	Si O2, Na9.6 ((Al9.6 Si38.4) O96), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84, Ca0.5(Al2 Si4 O11 (OH))
	39	Si O2, Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	41	Si O2, Ca0.5(Al2 Si4 O11 (OH))
	43	Si O2, Ca0.5(Al2 Si4 O11 (OH))
	46	Si O2, Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	47	Ca Al2((OH)8 (H_2O)2) (H_2O)1.84, Ca0.5(Al2 Si4 O11 (OH))
	48	Na9.6 ((Al9.6 Si38.4) O96), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	49	Ca Al2((OH)8 (H_2O)2) (H_2O)1.84, Ca0.5(Al2 Si4 O11 (OH))
	50	Si O2, Na9.6 ((Al9.6 Si38.4) O96), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	55	Si O2, Na9.6 ((Al9.6 Si38.4) O96) , Ca0.5(Al2 Si4 O11 (OH))
	57	Al_2O_3, Ca Al2((OH)8 (H_2O)2) (H_2O)1.84, Ca0.5(Al2 Si4 O11 (OH))
	60	Si O2, Ca Al2((OH)8 (H_2O)2) (H_2O)1.84, , Ca0.5(Al2 Si4 O11 (OH))
	64	Si O2
	68	Si O2, Na9.6 ((Al9.6 Si38.4) O96), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	69	Si O2, Na9.6 ((Al9.6 Si38.4) O96), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	74	Si O2
	76	Si O2
	80	Si O2, Na9.6 ((Al9.6 Si38.4) O96)
	82	Si O2
	85	Si O2

Tab. 11 Analysis of the XRD pattern for Soil treated with 2% Nano-Al2O3

Soil sample +2 %Nano-Al_2O_3	Peak	Formula from diffractogram
	2	Ca0.5(Al2 Si4 O11 (OH)), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	20	Ca0.5(Al2 Si4 O11 (OH)), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	21	Si O2
	23	Ca0.5(Al2 Si4 O11 (OH)), Na9.6 ((Al9.6 Si38.4) O96)
	26	Si O2, Ca0.5(Al2 Si4 O11 (OH))
	27	Na9.6 ((Al9.6 Si38.4) O96), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	29	Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	35	Al_2O_3, Ca0.5(Al2 Si4 O11 (OH)), Na9.6 ((Al9.6 Si38.4) O96), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	36	Ca0.5(Al2 Si4 O11 (OH)), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	37	Si O2, Ca0.5(Al2 Si4 O11 (OH)), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	38	Na9.6 ((Al9.6 Si38.4) O96)
	39	Na9.6 ((Al9.6 Si38.4) O96), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	40	Si O2, Ca0.5(Al2 Si4 O11 (OH))
	43	Si O2, Ca0.5(Al2 Si4 O11 (OH)), Na9.6 ((Al9.6 Si38.4) O96)
	44	Al_2O_3
	46	Si O2, Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	48	Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	49	Ca0.5(Al2 Si4 O11 (OH)), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	50	Si O2, Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	55	Si O2, Ca0.5(Al2 Si4 O11 (OH)), Na9.6 ((Al9.6 Si38.4) O96),
	58	Al_2O_3, , Ca0.5(Al2 Si4 O11 (OH)), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	60	Si O2, Ca0.5(Al2 Si4 O11 (OH)), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	62	Ca0.5(Al2 Si4 O11 (OH))
	64	Si O2, Na9.6 ((Al9.6 Si38.4) O96)
	67	Si O2, Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	68	Si O2, Na9.6 ((Al9.6 Si38.4) O96), Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	69	Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	74	Si O2, Ca Al2((OH)8 (H_2O)2) (H_2O)1.84
	76	Si O2, Na9.6 ((Al9.6 Si38.4) O96)
	80	Si O2, Na9.6 ((Al9.6 Si38.4) O96)
	81	Si O2
	82	Si O2
	84	Si O2

Nano-Al_2O_3 is contain one crystal phase, which is Al_2O_3 as showed in the table 8, that gives an indication that the Nano-Al_2O_3 used in this study was pure. In the case of soil treated with (0.5% and 1%) of Nano-Al_2O_3 the samples contain the crystal phases found in soils, see tables 9 and 10. When treated soil with 2% Nano-Al_2O_3, the XRD pattern results shows that the samples contain the crystal phase Aluminum Oxide.

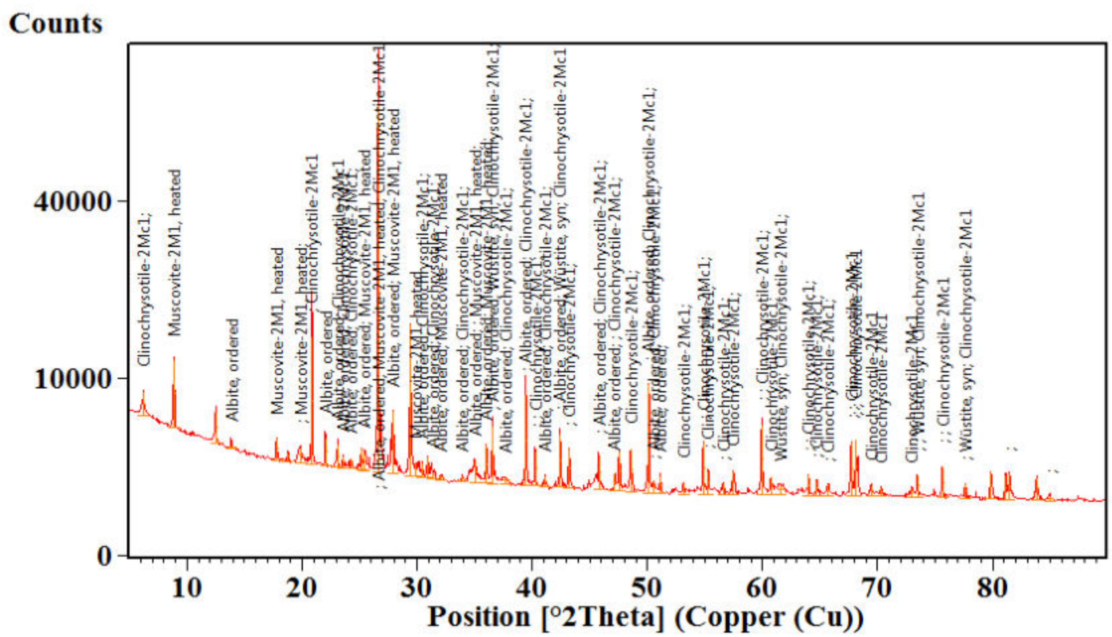


Fig. 31. The XRD pattern of the soil treated with 2% cement

Tab. 12 Analysis of the XRD pattern of the soil treated with 2% cement

Soil samples +2% cement	Peak	Formula from diffractogram
	2	Clinochrysotile-2Mc1
	8	Muscovite-2M1, heated
	14	Albite, Ordered
	18	Muscovite-2M1, heated
	20	Muscovite-2M1, heated
	21	Clinochrysotile-2Mc1
	23	Albite Ordered, Clinochrysotile-2Mc1
	24	Albite Ordered, Clinochrysotile-2Mc1
	25	Albite Ordered, Clinochrysotile-2Mc1

	27	Albite, Ordered, Muscovite-2M1 heated, Clinochrysotile-2Mc1
	28	Albite, Ordered, Muscovite-2M1 heated
	29	Muscovite-2M1, heated
	30	Albite Ordered, Clinochrysotile-2Mc1
	31	Albite Ordered, Clinochrysotile-2Mc1
	33	Albite Ordered, Clinochrysotile-2Mc1
	34	Albite Ordered, Clinochrysotile-2Mc1
	35	Albite Ordered, Muscovite-2M1, heated
	37	Albite Ordered, Muscovite-2M1, heated
	38	Albite Ordered, Clinochrysotile-2Mc1
	39	Albite Ordered, Clinochrysotile-2Mc1
	40	Albite Ordered, Clinochrysotile-2Mc1
	41	Clinochrysotile-2Mc1
	42	Clinochrysotile-2Mc1
	43	Albite Ordered, Muscovite-2M1, heated, Clinochrysotile-2Mc1
	44	Clinochrysotile-2Mc1
	46	Albite Ordered, Clinochrysotile-2Mc1
	47	Albite Ordered, Clinochrysotile-2Mc1
	48	Clinochrysotile-2Mc1
	50	Albite Ordered, Clinochrysotile-2Mc1
	51	Albite Ordered
	53	Clinochrysotile-2Mc1
	55	Clinochrysotile-2Mc1
	56	Clinochrysotile-2Mc1
	57	Clinochrysotile-2Mc1
	58	Clinochrysotile-2Mc1
	60	Clinochrysotile-2Mc1
	61	Wustite, Clinochrysotile-2Mc1

	62	Clinochrysotile-2Mc1
	63	Clinochrysotile-2Mc1
	64	Clinochrysotile-2Mc1
	67	Clinochrysotile-2Mc1
	68	Clinochrysotile-2Mc1
	70	Clinochrysotile-2Mc1
	71	Clinochrysotile-2Mc1
	72	Clinochrysotile-2Mc1
	74	Clinochrysotile-2Mc1
	75	Wustite, Clinochrysotile-2Mc1
	76	Clinochrysotile-2Mc1
	78	Wustite, syn, Clinochrysotile-2Mc1

In the case of the soil samples treated with cement, a new crystal phase appears (wustite) besides the phases characteristic of the soil.

1.4.1.3 The pH test

The effect of Nano-Al_2O_3 on the pH was investigated to evaluate the chemical reaction of the nanomaterial on the treated. Soil samples as shown in figure 32. The results showed that there is a very small change in the value of the pH of the treated soils.

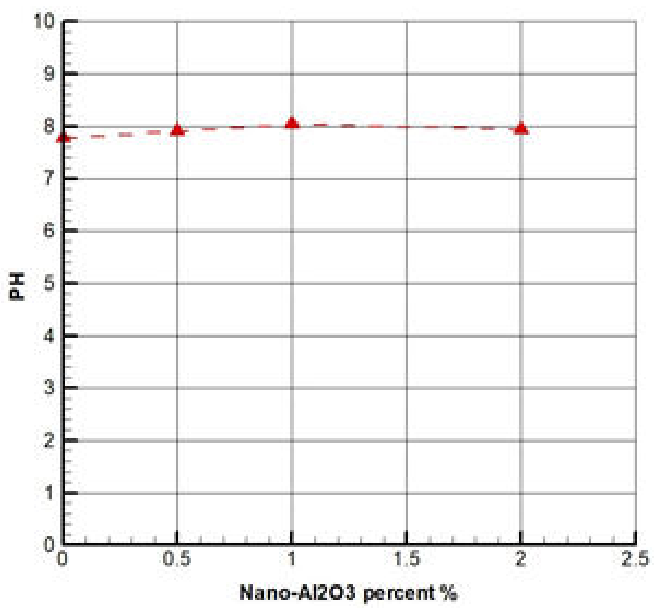


Fig. 32. pH for different Nano-Al_2O_3 percentages after mixing with soil samples

1.4.2 Effect of nanomaterial on the physical and mechanical properties of the soil

1.4.2.1 Classification and grain size distribution

All the soil samples were classified according to the texture classification system. The Results of the grain size distribution according to (STAS 1913/5-1985) [16], showed that the natural soil sample consist of 61% silt, 24% clay and 15% sand.

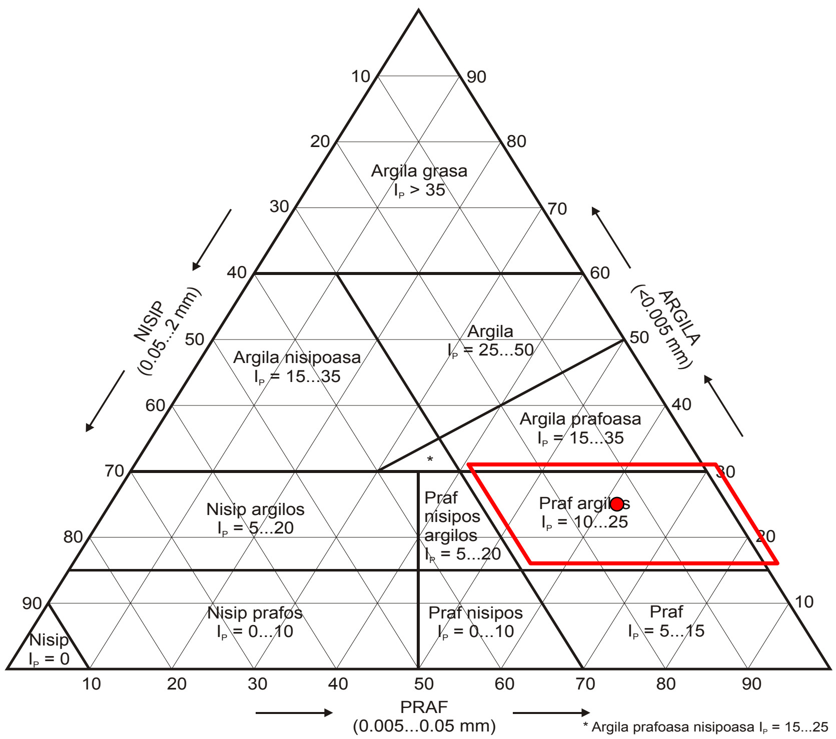


Fig. 33. Texture classification system of silty clay (loess)

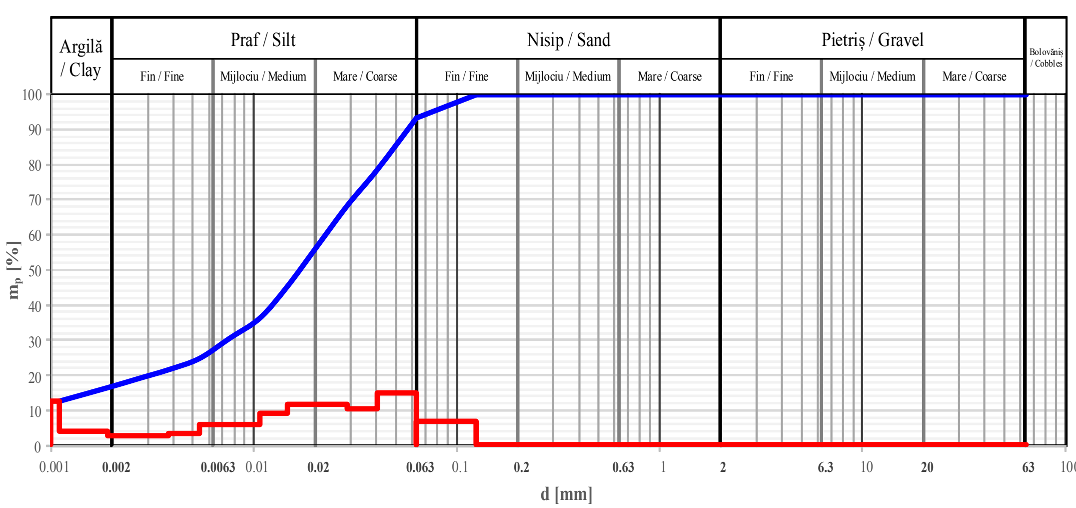


Fig. 34. Grain size distribution curve for non-treated soil

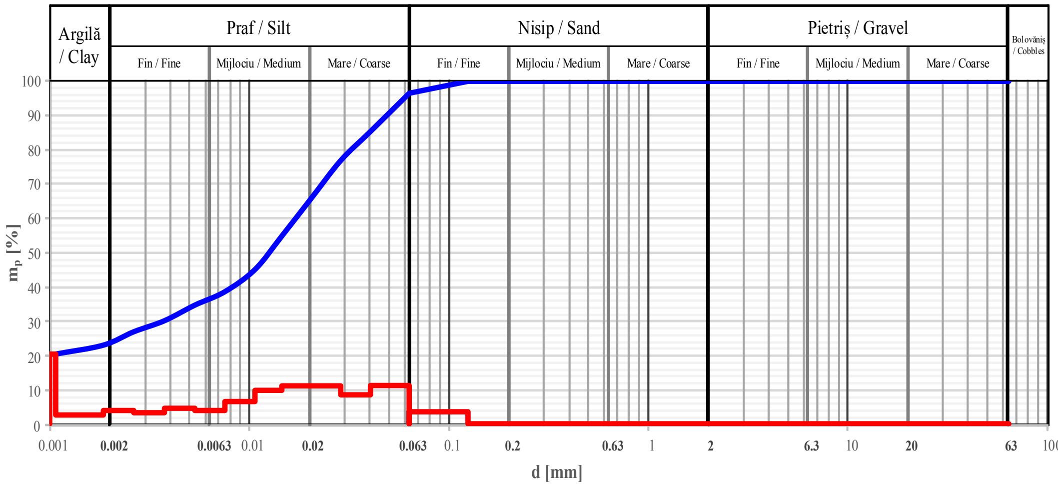


Fig. 36. Grain size distribution curve for soil treated with 0.5% Nano-MgO

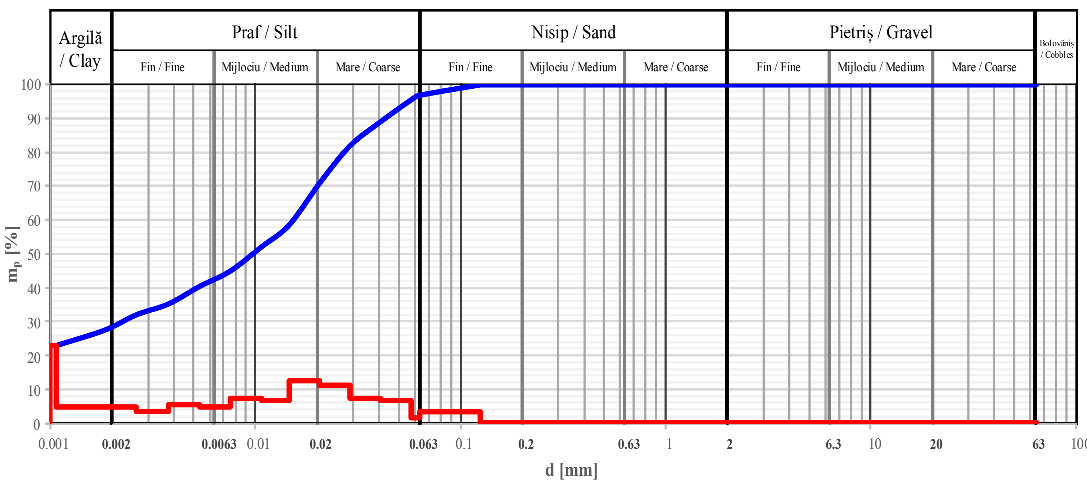


Fig. 35. Grain size distribution curve for soil treated with 0.75% Nano-MgO

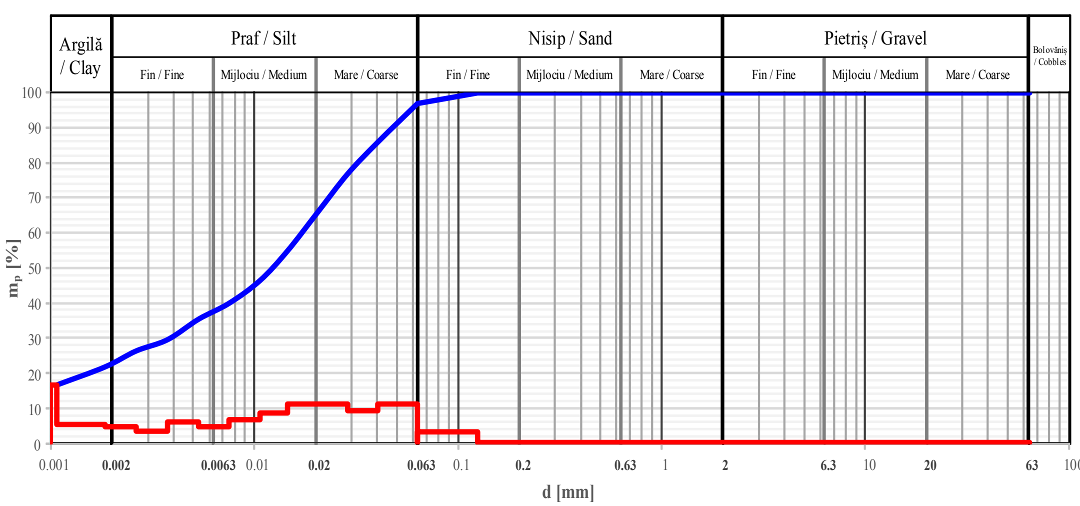


Fig. 37. Grain size distribution curve for soil treated with 1% Nano-MgO

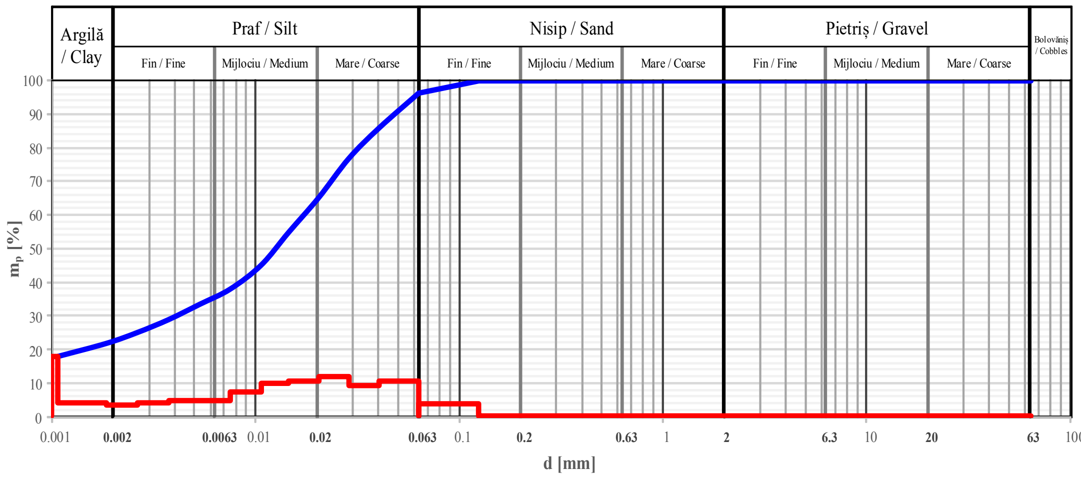


Fig. 38. Grain size distribution curve for soil treated with 2% Nano-MgO

1.4.2.2 Atterberg limit

The liquid limit (LL), plastic limit (PL) and plasticity index (PI=LL-PL) of the soil samples treated with (0.5%,0.75%,1%,and 2%) Nano-MgO, Nano-Al_2O_3 with percentages (0.5%,1%, and 2%) and 2% cement were determined according to (STAS 1913/4-1986) [17]. The addition of Nano-MgO and Nano-Al_2O_3 to the soil samples have a small effect on the Atterberg limits. These small decreases in the value of liquid limits and plastic limits as shown in figure 32 a and b. Due to the change in water content because of the additivities. On the other hand there is an increase in the value of the consistency index when increase the addition of the Nano-MgO and Nano-Al_2O_3 a, until reaching the optimum amount of nanomaterials. After which adding more amount of Nano-MgO will affect negative on soil properties and leads to decrease in the value of the consistency index because of the formation of voids due to the agglomeration of the nanomaterial's particles in the soil, the optimal amount was less than of 1% nano-MgO to the dry weight of the soil. as a result the adding of nanomaterials and cement are surround the clay clast in the soil and work to binding them and filling the tiny pores and improving the clay matrix, thus reducing the voids and water content [18]. This gives some indication pf improvement soil properties.

Fig. 39. Atterberg limits tests for non-treated and treated soil with different percentage of Nano-MgO a) Liquid limit test b) Plastic limit test

Fig. 40. Aterrberg limits test

Tab. 13 plasticity Index for soil samples treated with different percentage of Nano-Mgo

Type and percent of additive	Non treated soil	0.5% nanomgo	0.75% nanomgo	1% nanomgo	2% nanomgo
Plasticity Index	18	22	21	21	21

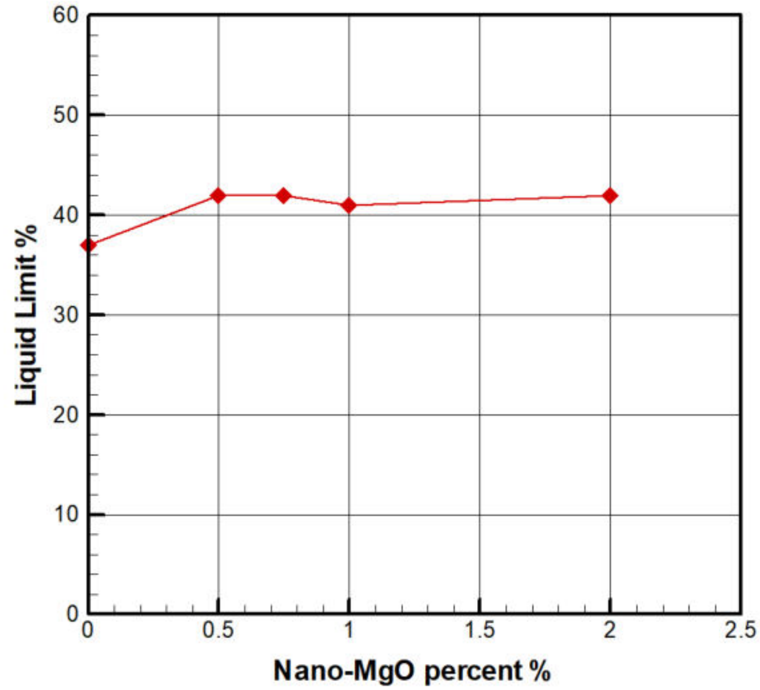


Fig. 41. The effect of Nano-MgO on the Liquid limit for soil with different percentage of Nano-MgO

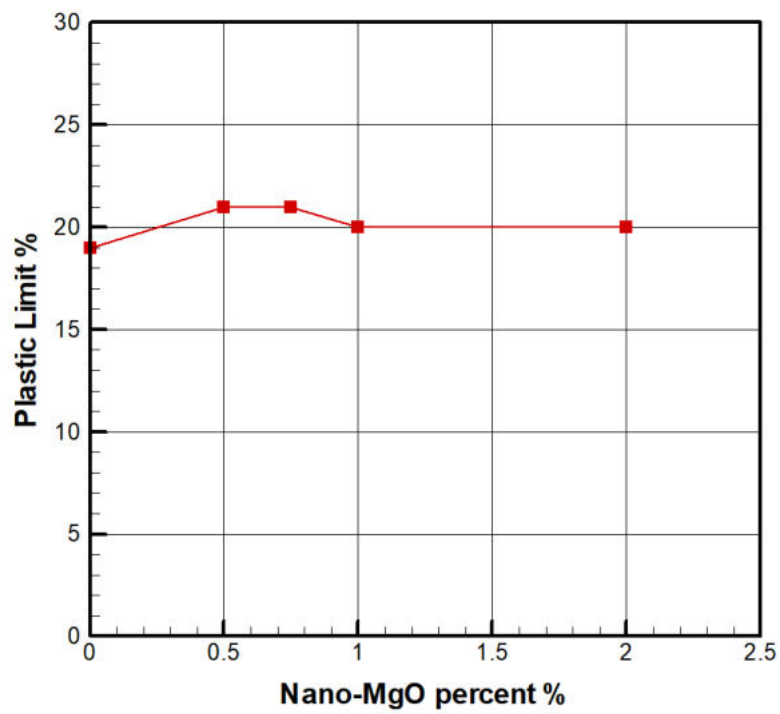


Fig. 42. The effect of Nano-MgO on the plastic limit for soil with different percentage of Nano-MgO

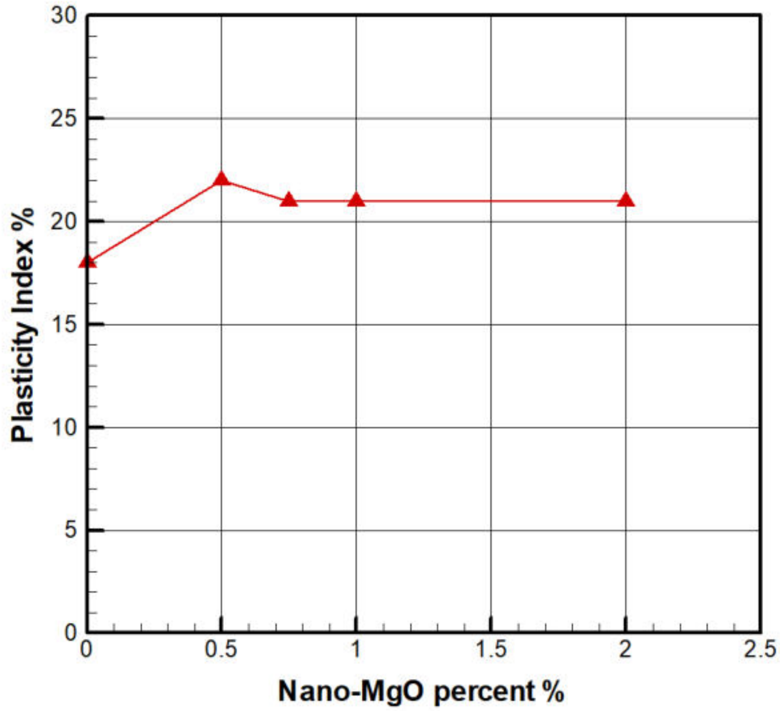


Fig. 843. The effect of Nano-MgO on the plasticity index for soil with different percentage of Nano-MgO

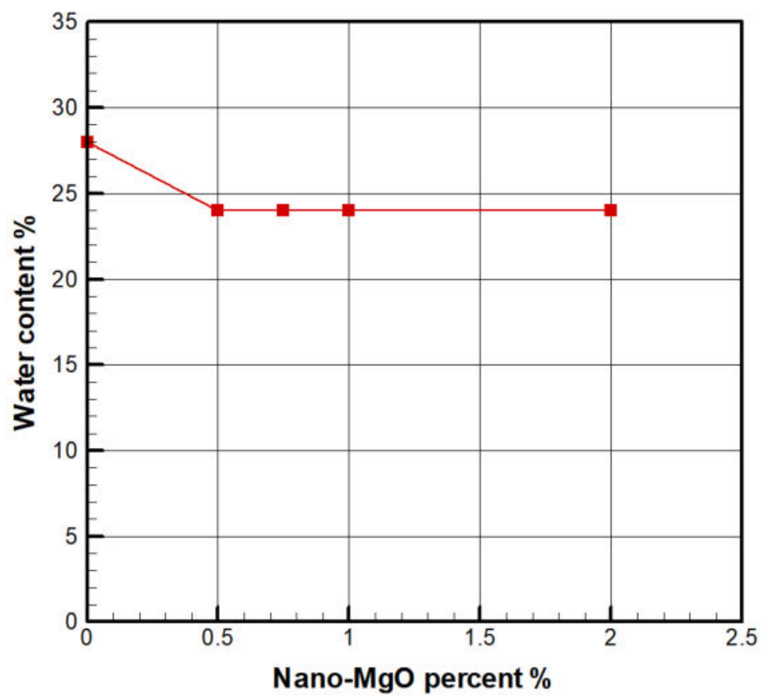


Fig. 44. The effect of Nano-MgO on the water content for soil with different percentage of Nano-MgO

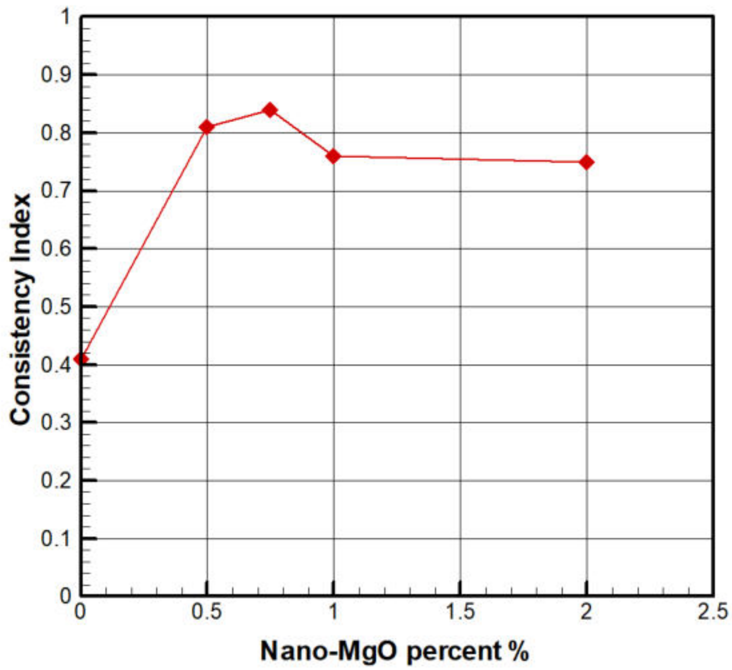


Fig. 45. The effect of Nano-MgO on the consistency index for soil with different percentage of Nano-MgO

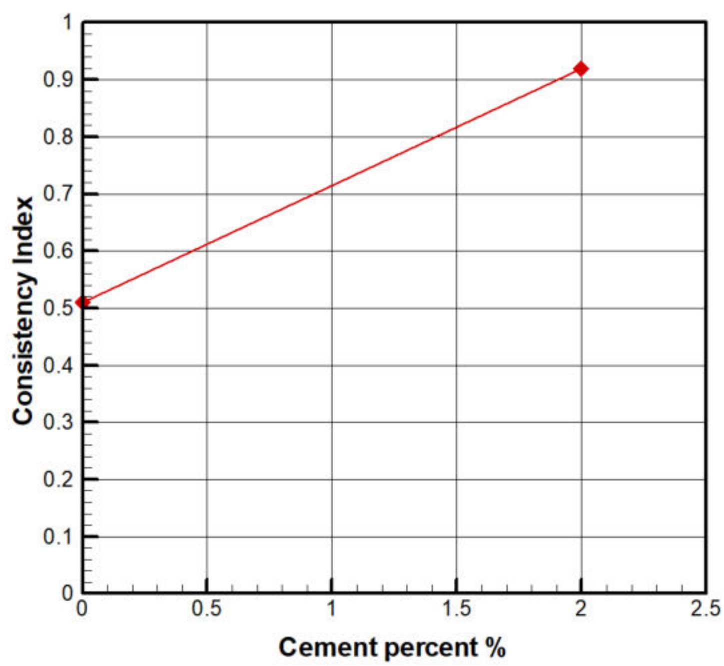


Fig. 46. Consistency index for soil treated with 2%cement

1.4.2.3 Oedometer test

Oedometer test is performed by applying different loads on a sample of the soil to determine the magnitude and the rate of consolidation and measuring the deformation. The soil sample will be loaded and unloaded, and the results which are obtained in this test will be used to predict about the deformation that will occur to the soil in the field [19].

The soil specimen is placed into a metal ring which prevents any lateral displacement and allow to the sample to compress or swell vertically, according to the applied load and set up in the oedometer apparatus, vertical drainage is allowed during the porous stone on the top and the bottom of the specimen and one-dimensional pressure is subjected, while changes in thickness are recorded against time [20].

The soil samples taken from the study area were compacted by using a modified Proctor procedure and tested according to (STAS 1913/13-83) [21] and (SR EN ISO 13286-2: 2011) [22]. Oedometer test was performed according to (STAS 8942/1-89) [23]. Compression tests were performed to study the influence of the additives (i.e., Nano-MgO, Nano-Al_2O_3 and cement in this study) in improving the compressibility of the soils. The results show that there is some improvement, and the parameter of the compressibility of the soil samples increase with increasing the amount of the Nano-MgO. and Nano-Al_2O_3 as shown in figures 33 and 35.but there is a much more improvement when we compare the untreated soil with soil mixed with 2%cement, as shown in figure 34.

Tab. 14 Oedometer modulus Eoed (kPa) of the soil samples treated with different percentage of Nano-MgO

Type and percent of additive	Non treated soil	0.5% Nanomgo	0.75% nanomgo	1% nanomgo	2% nanomgo	2% cement
Oedometer modulus E_{oed} (kPa)	4080	5900	6490	7870	9660	11000

Tab. 15 Oedometer modulus of the soil samples treated with different percentage of Nano- Al2O3

Type and percent of the additive	Non treated soil	0.5% Nano-Al_2O_3.	1% Nano- Al_2O_3.	2% Nano- Al_2O_3.
Oedometer modulus E_{oed} (kPa)	12000	12195	13423	21000

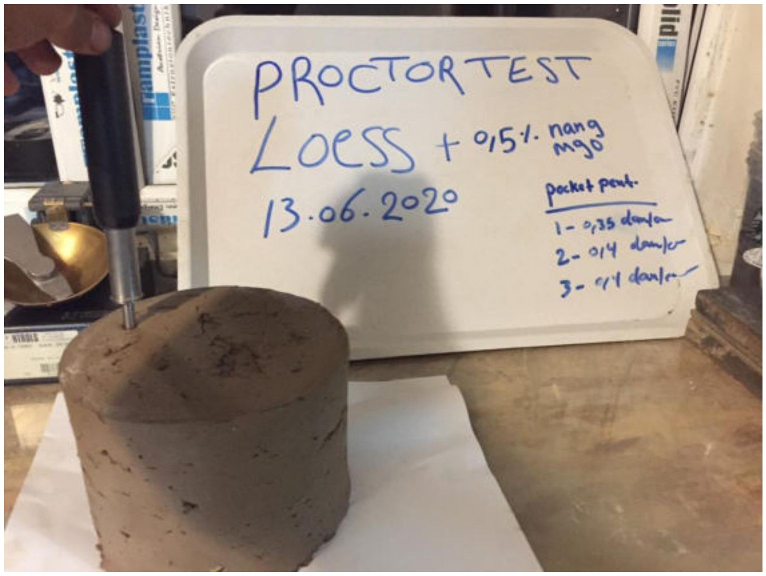


Fig. 47. soil sample treated with 0.5% Nano-MgO after compaction

Fig. 48. Oedometer test

Fig. 49. oedometer test for soil samples treated with different percentages of nanomaterials.

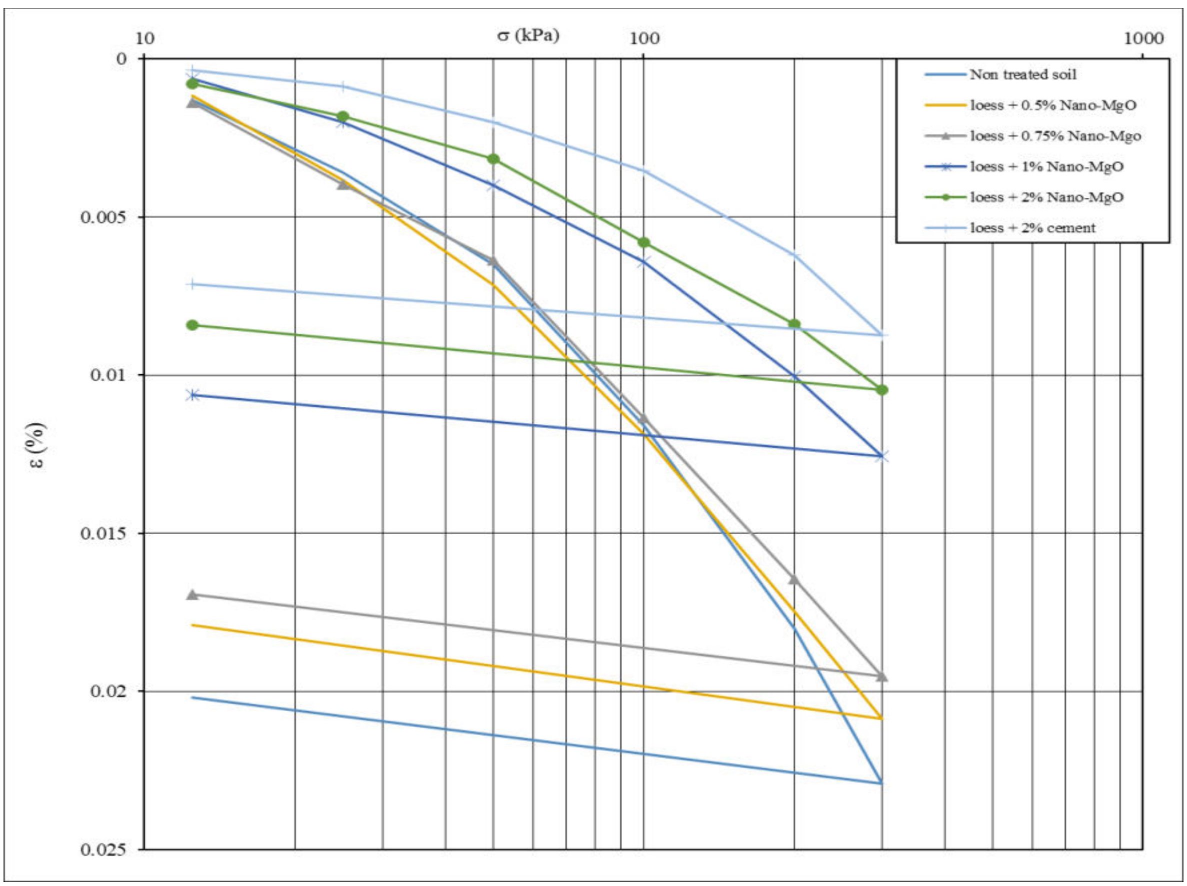


Fig. 50. Edometric curves for soil samples collected from Perisoru and treated with different percentages of Nano-MgO

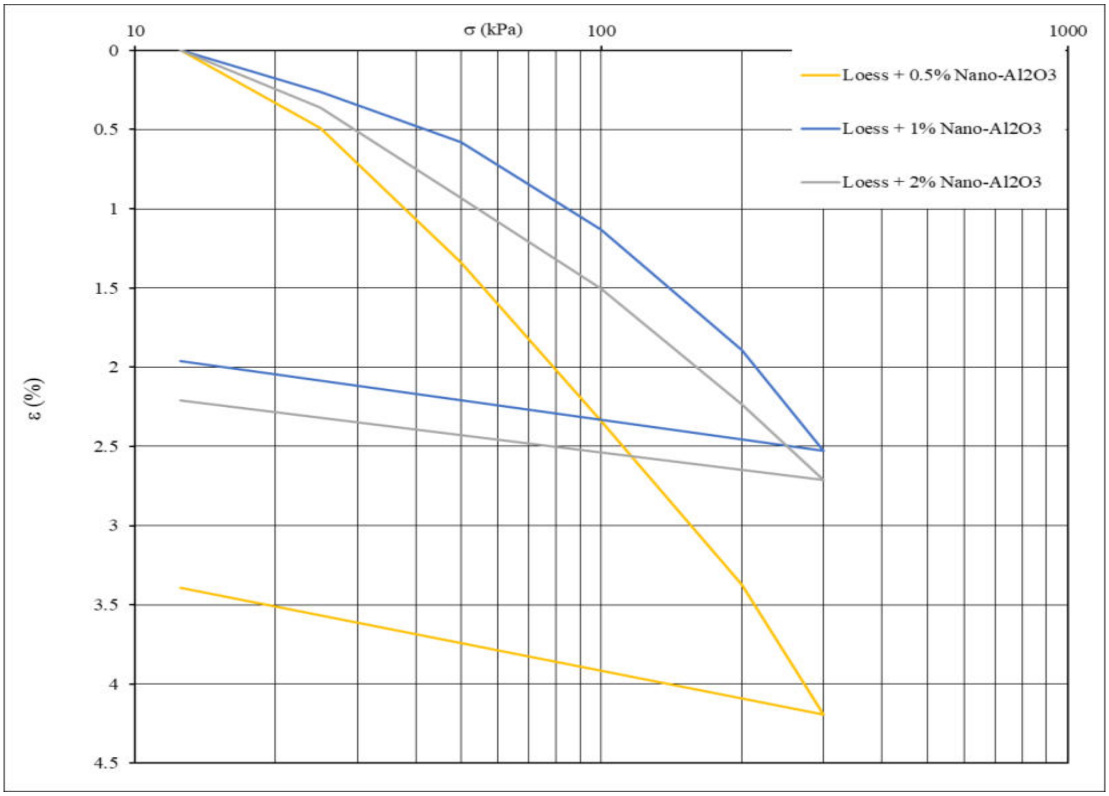


Fig. 51. Edometric curves for soil samples collected from Viisoara Sud and treated with different percentages of Nano-Al_2O_3.

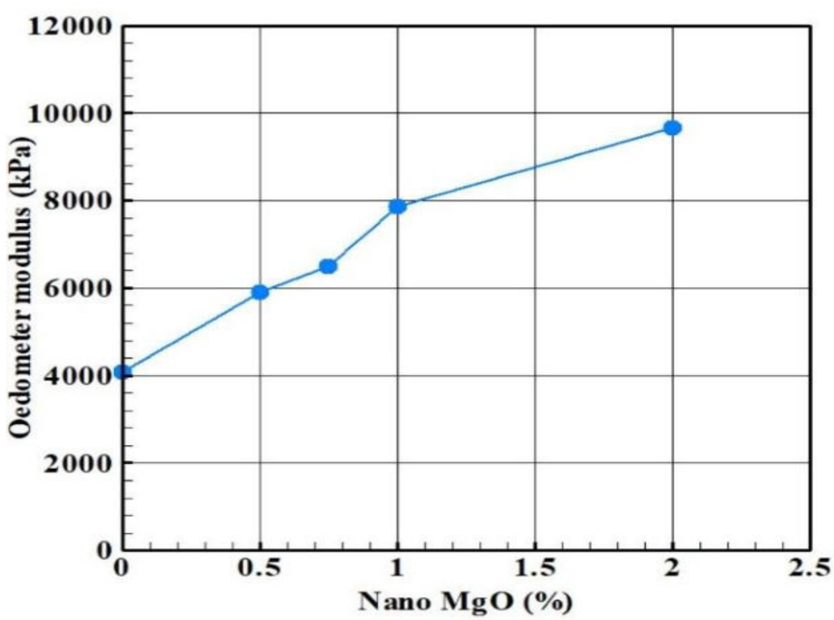


Fig. 52. Oedometer modulus Eoed (kPa) for soil mixed with Nano-MgO

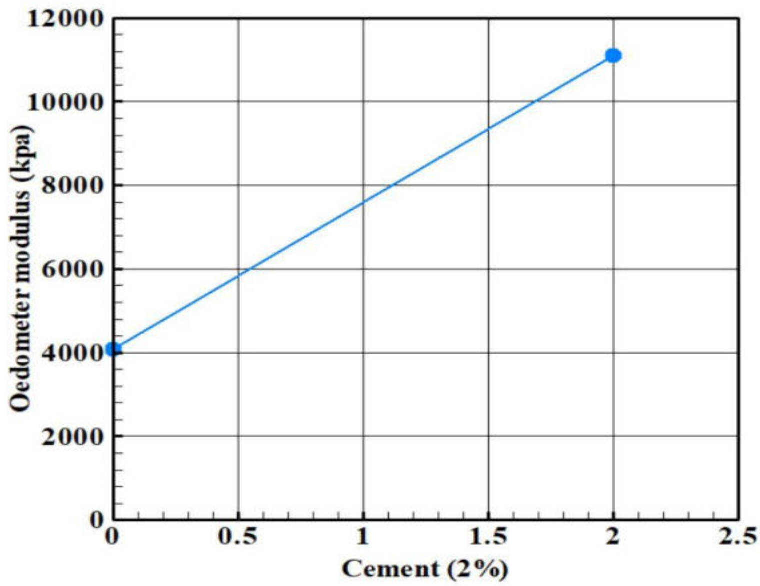


Fig. 53. Oedometer modulus Eoed (kPa) for soil mixed with cement

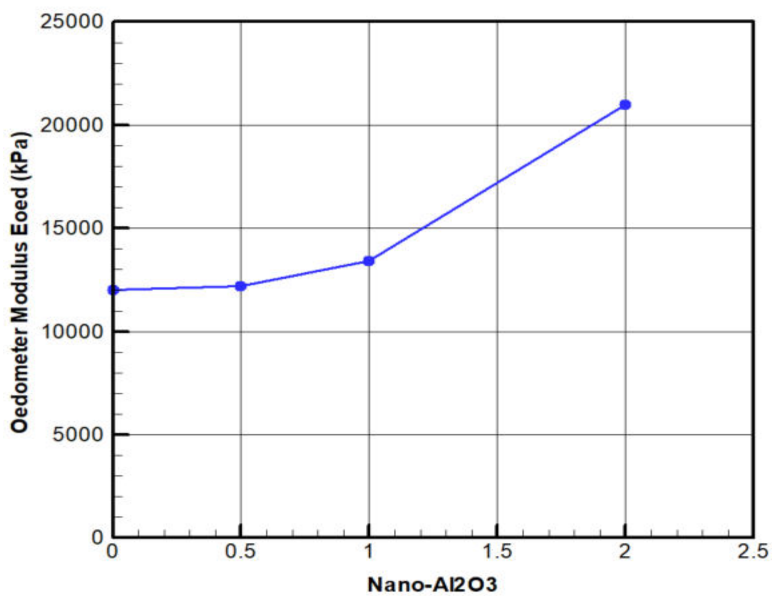


Fig. 54. Oedometer modulus Eoed (kPa) for soil mixed with Nano-Al_2O_3

1.4.2.4 Direct shear test

Consolidated drained (CD) direct shear tests have been done according to (STAS 8942, 2-1982) [7] to determine the effective shear strength parameters the friction angle (ϕ') and the cohesion (c') for undisturbed or remolded samples.

The strength of the soil depends on its resistance to shearing stresses and it is made up of two components frictional (due to friction between particles), and cohesive (due to the adhesion between soil particles), which is a major interest in the design of different geotechnical structures. The chemical additives have a sharp effect on the friction angle [24], that which is increased with increasing the amount of nanomaterials as shown in Tab. 16 below:

Tab. 16 Results of direct shear tests for soil samples treated with a different percentage of Nano-MgO

Type and percent of additive	**the friction angle** (ϕ')◦	**the cohesion** (c') **kpa**
Non-treated soil	16◦	15
0.5 % Nano-Mgo	16◦	15
0.75% Nano-Mgo	19◦	14
1% Nano-Mgo	20◦	20
2 % Nano-Mgo	22◦	28

Normal Stress versus Shear stress for soil treated with 0.5% Nano-MgO

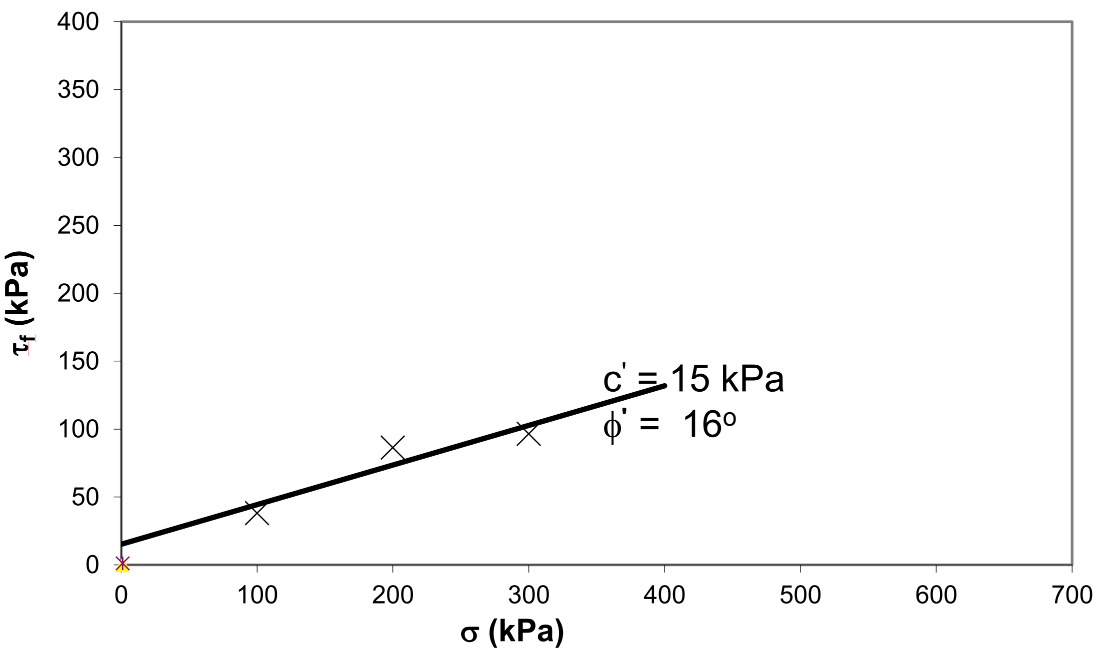


Fig. 155. Normal Stress versus Shear stress for soil treated with 0.5% Nano-MgO

Normal Stress versus Shear stress for soil treated with 0.75% Nano-MgO

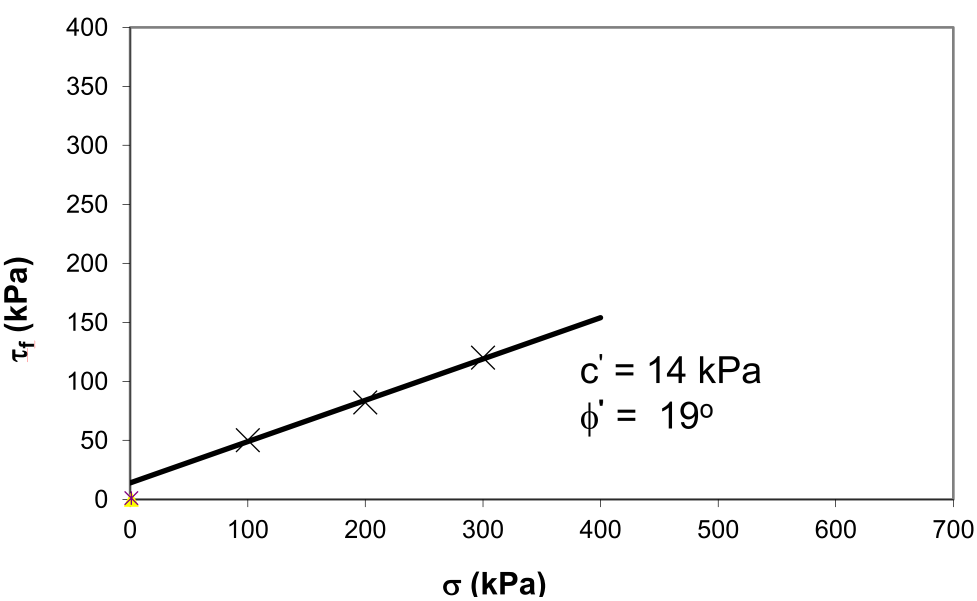


Fig. 56. Normal Stress versus Shear stress for soil treated with 0.75% Nano-MgO

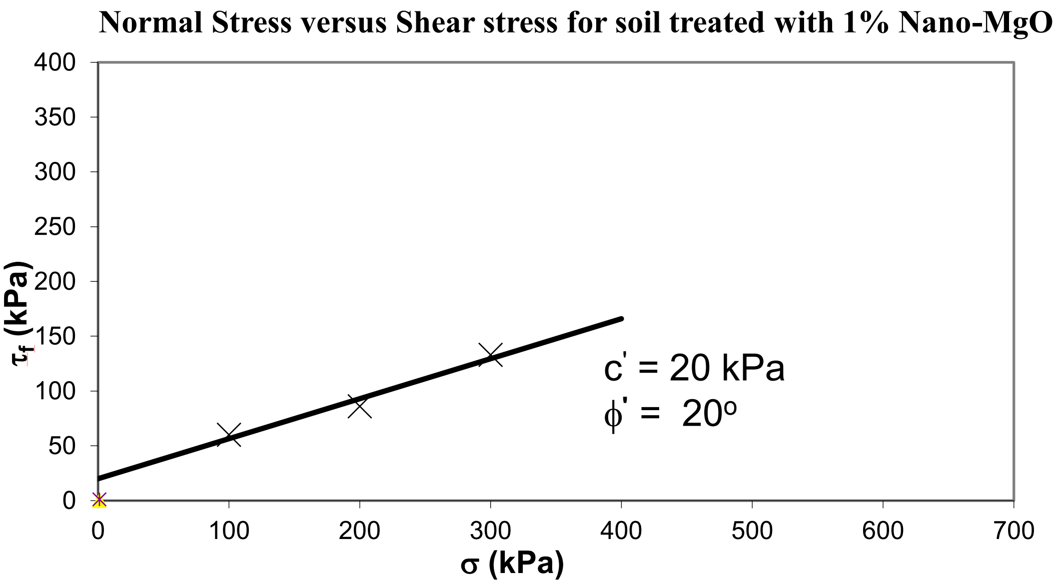


Fig. 57. Normal Stress versus Shear stress for soil treated with 1% Nano-MgO

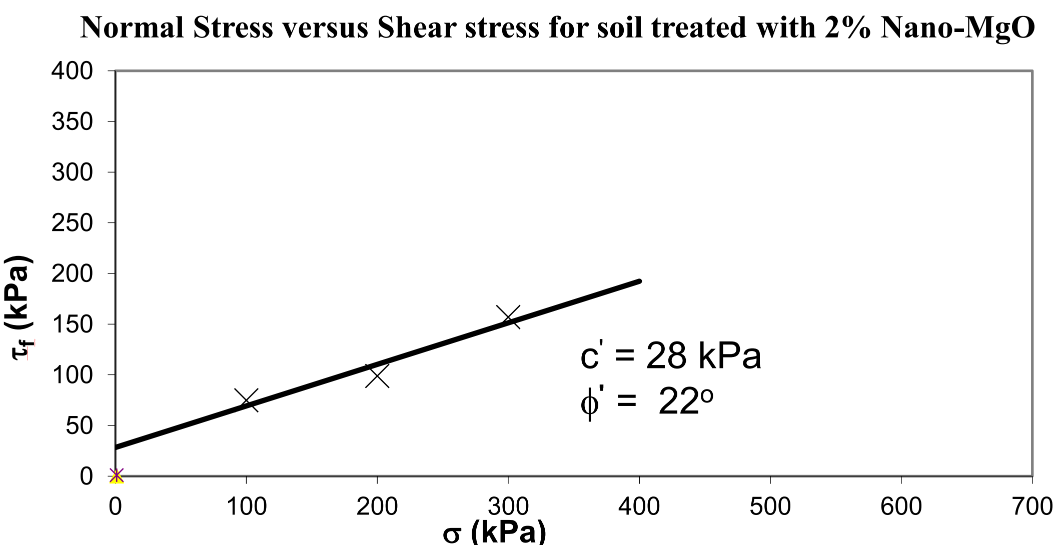


Fig. 58. Normal Stress versus Shear stress for soil treated with 2% Nano-MgO

1.5 Conclusion

This study investigated experimentally the effect of different types of nanomaterials on the geotechnical properties of soils collected from two different sites in Romania. Two different types of nanomaterials were used in this research, which are namely Nano-MgO with different percentages (0.5%, 0.75%, 1%, and 2%), and Nano-Al_2O_3 with percentages (0.5%,1%, and 2%).

The improvement soil properties using nanomaterials depends on the type and the amount of these materials. Insoluble nano materials, like nano-MgO show a small chemical effect on the soil as the results of the Scanning Electron Microscopy showed, thus, the using of nano-magnesium oxide had a small effect on the properties of the soil.

From the analysis of the results obtained with SEM, we can observe that a visible change in the microstructure of the samples, occurs especially on the soil samples mixed with 2% Nano Al_2O_3. In the case of 0.5% and 1%, the microstructure of soil-nano-alumina mixtures indicated that the new phase formed by adding Nano Al_2O_3 had a small interaction and consisted of some new bonds between the particles of the soil samples.

The results showed that There was a small effect on the Atterberg limits, there are little decreases in the value of the liquid limit and plastic limit, the compressibility of the soil increased with an increase in the amount of added nanomaterials for both soils, Also, observed that the shear strength of the soil increased with increase the amount of nanomaterials.

As a result, we can conclude that the nanomaterials may help to improve the geotechnical properties of the soil, but, from a technical point of view, they had little impact on the geotechnical properties of the soil. Also, from the economical point of view, compared to other and common chemical additives like cement, they are an expensive option. They may work well as an additive to cement mixing technologies

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