Journal of Geotechnical Geology
Zahedan Branch, Islamic Azad University
Vol.12 (2016), No.2 (157-167)
geotech.iauzah.ac.ir

Zahedan Branch,
Islamic Azad University

Improvement of CL soil engineering properties by using of silica and kaolinite nanoparticles

Moharram, Majidi[1]*, Ali, Uromiei[1], Mohamadreza, Nikudel[1]

1) Department of Engineering Geology, Tarbiat Modares University, Tehran, Iran

*Corresponding Author

Received: 30 Jul. 2016; accepted 15 Dec. 2016; available online: 25 May. 2017

Abstract

In this study, the effect of nanosilica and nanokaolinite particles on geotechnical properties of clayey soils is investigated. The mechanical method of Planetary Ball Mill was used for nanoparticles production. In this process, initial silicate and kaolinite powders was milled in Planetary Ball Mill for 10 hours with speed of 500 Rpm. This product was in nanometer scale and FESEM images prove it. In next stage, nanoparticles were mixed with clayey soil (CL) in different weight ratio of dry soil then geotechnical properties of treated soils was determined by compaction, direct shear, cassagrande and unconfined compression tests and optimum percentage of added nanosilica and nanokaolinite obtained. As a result we understood LL and PL of soil increased while percentage of added nanoparticles increased but increasing of PL is more than LL, thus PI is decreased that is proper in geotechnical engineering for construction. Also compaction tests results was shown the density of clayey soil was increased by adding of nanoparticles with specific amount and higher than that the density would be decreased. Direct shear tests has been proved, cohesion of clayey soils increased by adding of specific amount of nanoparticles to optimum and there is no more change by increasing the nanoparticles. Results of unconfined compression tests indicated that compressive strength of amended soils could be raised up to 3 times more than unamend soil by adding nanoparticles. Results of XRD and XRF tests showed that chemical attribute of nanoparticles produced by planetary ball mill is same as initial material.

Keywords: nanoparticles, soil stabilization, ball milling, geotechnic

1. Introduction

Nanoparticles are microstructures minimum one dimension of which is in nanometer scale (National Nanotechnology Initiative 2007, Royal Society 2004). In nanoscale, electronic, magnetic, optic and chemical properties are changed while it cannot exist in macroscale (zhang 2007, zhang et al. 2004). Main properties of nanoparticles are small size, particle size distribution with low level of agglomeration and large dispersity (Thomas et al. 2007). Unique features of nanoparticles highlighted their presence in many sciences to dissolve many problems. Fortunately, geotechnic science benefits from nanotechnology too and in recent years, many studies are undertaken in this regard. Numerous studies have been conducted regarding use of nanoparticles for improving in soil strength parameters. The nanomaterials which have been more frequently used for changing the geotechnical properties are silica nanoparticles influencing the consolidation, permeability indices, and strength properties of soil (Majeed and Taha 2011). In 1992, Yonekura and Miwa utilized silica nanoparticles to increase sand compressive strength. Also, Noll et al. (1992) investigated the use of silica nanoparticles for enhancing strength of soil against consolidation and permeability. In 2005, silica nanoparticles were utilized by Gallagher and Lin for increasing soil's cohesion/adhesiveness and decreasing its viscosity then behavior of the sand improved by nanomaterials was analyzed in cyclic loading conditions. As a result, it was indicated that cohesion/adhesiveness depends on percentage of nanoparticles increase (Gallagher and Lin 2005). In 2007, Gallagher et al. in the United States used nanomaterials practically in a place the soil of which was of sand type with high viscosity and reported 40% improvement in settlement after applying artificial earthquake and evaluation of the yielded settlement. To study the effect of silica nanoparticles in dimension range of 5-100 nm, Butron (2009) carried out oedometer test, triaxial test, and compressive test, and showed that soil strength increases with time such that the soil containing nanoparticles is ductile in initial stages and subsequently becomes elastoplastic. In 2007, Zhangh indicated that existence of nanostructure in soil causes an increase in Atterberg limits. Zaid Hamid Majeed et al. (2014) used the nano-copper, nanoclay and nano-magnesium to stabilization of soft soil and results of the investigation showed significant improvement in maximum dry density, plasticity index, linear shrinkage and unconfined compressive strength. Firoozi et al. (2014) studied on assessment of nano-zeolite on soil properties and found that the Attererg,s limits vary with addition of different percenteage og nano-zeolite. From engineering perspective, soil existed in the site is not quite suitable for construction and needs to be modified. One of the best approaches in application of improper soil in geotechnique is changing properties of the soil which is called soil improvement Soil improvement is a set of changes that eliminate maltreatment of soil or imposing better treatment to it. One of the methods in this regard is adding cement or chemical additives to the soil structure (Das, 2010). Some of the additives which have been used to be applied are cement, tar, volcano ashes, and so on. Addition of them to soil reduces plasticity and swelling and improves its density, resistance and consistency after stabilization. Most of the material are used for stabilizing of fine grained soil and if they can be applied for coarse grained soil, reduces penetration and erosion while increase durability (Kadivar et al. 2011). One of the main problems in such additives to soil is contamination. Nevertheless, application of nanoparticles reduces such impact. Moreover, application of them in soil improvement result in controlling its resistance, reducing application of cements and consequently gaining economical advantages (Michael and Hochella 2002). In this study, the effect of adding nanosilica and nanokaolinite, which have been produced based on mechanical method, to geotechnical properties of clayey soil is investigated by using result of compaction, casagrande, direct shear and uniaxial strength tests.

2. Materials and methods

2.1 Used materials

2.1.1 Clayey soil:

Clayey soil in this study is taken from Parand station subway. Diagram of grain size of this soil is showed in figure 1. Results of XRD and XRF tests of soil are showed in figure 2 and table 1, respectively. Also results of physical tests on clayey soil are showed in table 2. This soil is CL in Unified category.

2.1.2 Nanoparticles

Used nanoparticles in this study are nanosilica and nanokaolinite that are produced by Planetary Ball Mill and images of them by FESEM microscope verify that particles reached to nanometer scale by this method (Fig.3). The initial silica and kaolinite powders were produced from Tabriz ceramic tile industry and purity percent of them were more than %99. Results of XRD and XRF tests on initial silica and kaolinite powders and nanoparticles that produced them showed no change in chemical composition of them in milling processing and this is a benefit of mechanical method of producing nanoparticles. Figure 4 and table 3 show the results of XRD and XRF tests on nanosilica and nanokaolinite respectively and table 4 show the quantity of effective parameters for producing the nanoparticles by planetary ball mill.

2.1.3 water

The used water in this study is distilled water for all tests.

2.2 Laboratory tests

2.2.1 Standard compaction test based on ASTM D: 698-78

For preparing samples to do standard compaction tests, first different percentages of nanoparticles (0.5, 1, 1.5 and 2% weight of dry soil) were mixed with distilled water and put in ultrasonic bath for 30 minutes to disperse nanoparticles in water homogenously and prevent agglomeration of nanoparticles, then sprayed the suspension to total volume of soil and mixed with turbo mixer for 30 minutes to provide homogenous composition of soil and nanoparticles and samples without clogging. Producing homogenous sample is much more important and effective part of the test as accuracy of test results is absolutely dependent on the homogeneity of sample. Turbo mixer rotates in 3 space direction such as orbital motion with 60 Rpm speed and causes nanoparticles disperse homogenously in soil volume. Samples were put in brake bag to preserve humidity for 24 hours to perform chemical reaction between soil particles and nanoparticles then their effects are investigated. After 24 hours, soil compaction test was done on prepared samples based on ASTM D: 698-78. In order to control the results and investigating the effects of nanoparticles on soil, test results of untreated sample is used. Results of compaction test on soil with different dosages of nanoparticles and their effect on

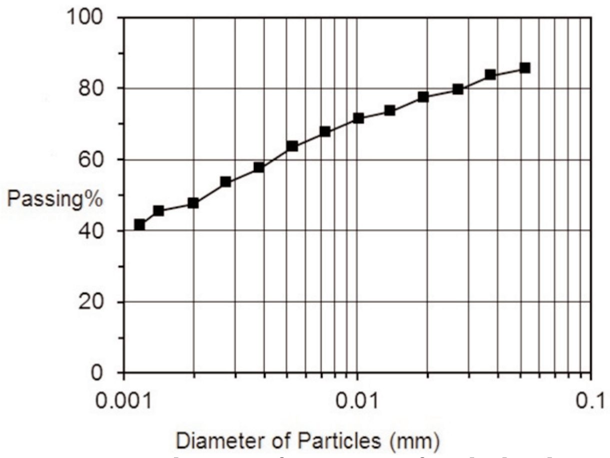


Figure 1. diagram of grain size of studied soil

Table 1. chemical composition of clayey soil by XRF test

Fe_2O_3	Mno	Tio_2	Cao	K_2O	So_3	P_2O_5	Sio_2	Al_2O_3	Na_2O	L.O.I	Oxides
4.717	0.372	0.539	9.627	4.221	4.078	0.175	50.954	13.548	1.547	9.75	%

Table 2. physical properties of studied soil

color	category	Gs	LL	PL	PI	γd_{max}(KN/m3)	%W	C(Kpa)	??
yellow	CL	2.7	32	19	13	17.26	16.85	13	11

compaction properties (maximum dry density and optimum water content) are shown in figures 5 and 6.

As shown in figure 5, adding nanokaolinite to 1% and nanosilica to 1.5% weight of soil causes increasing density of CL soil (because of substitution of nanoparticles instead of air in nanopores). Adding nanoparticles more than above limits causes decreasing of soil density because nanoparticles agglomerate together and form aggregate then decrease weight unit of soil. Also, with attention to figure 6, increasing dosage of nanoparticles in soil composition causes increasing of optimum humidity content of soil that is the result of positioning nanoparticles in nanopores and attraction of interparticle and intraparticle water and absorption of hydrated iones of water due to high surface charge of nanoparticles.

2.2.2 Cassagrande tests based on ASTM D: 4318-87

Similar to compaction test, for preparing test samples, different dosages of nanoparticles were added to CL soil and for homogenizing sample used from turbo mixer. A little water was sprayed to composition and cured for 24 hours in brake bag in order to provoke chemical reactions between soil and nanoparticles and be prepared for test. Liquid limit and Plastic limit tests performed on composition of soils with different dosages of nanoparticles and results obtained as shown in figure 7.

As shown in figure 7, with increasing of nanoparticle dosage in soil composition, liquid limit and plastic limit increased due to high ratio of area to volume in nanoparticles and activity of them in addition to the positioning of nanoparticles in nanopores of soil and then increasing of water capacity in soil. Results showed that rate of increasing of plasticity limit (PL) is more than rate of increasing of liquidity limit (LL); thus, Plastisity index (PI=LL-PL) is reduced when dosage of nanoparticle is increased.

2.2.3 Direct shear test based on ASTM D: 3080-90

Preparation of samples is similar to compaction test procedure. Content of water used to mix with

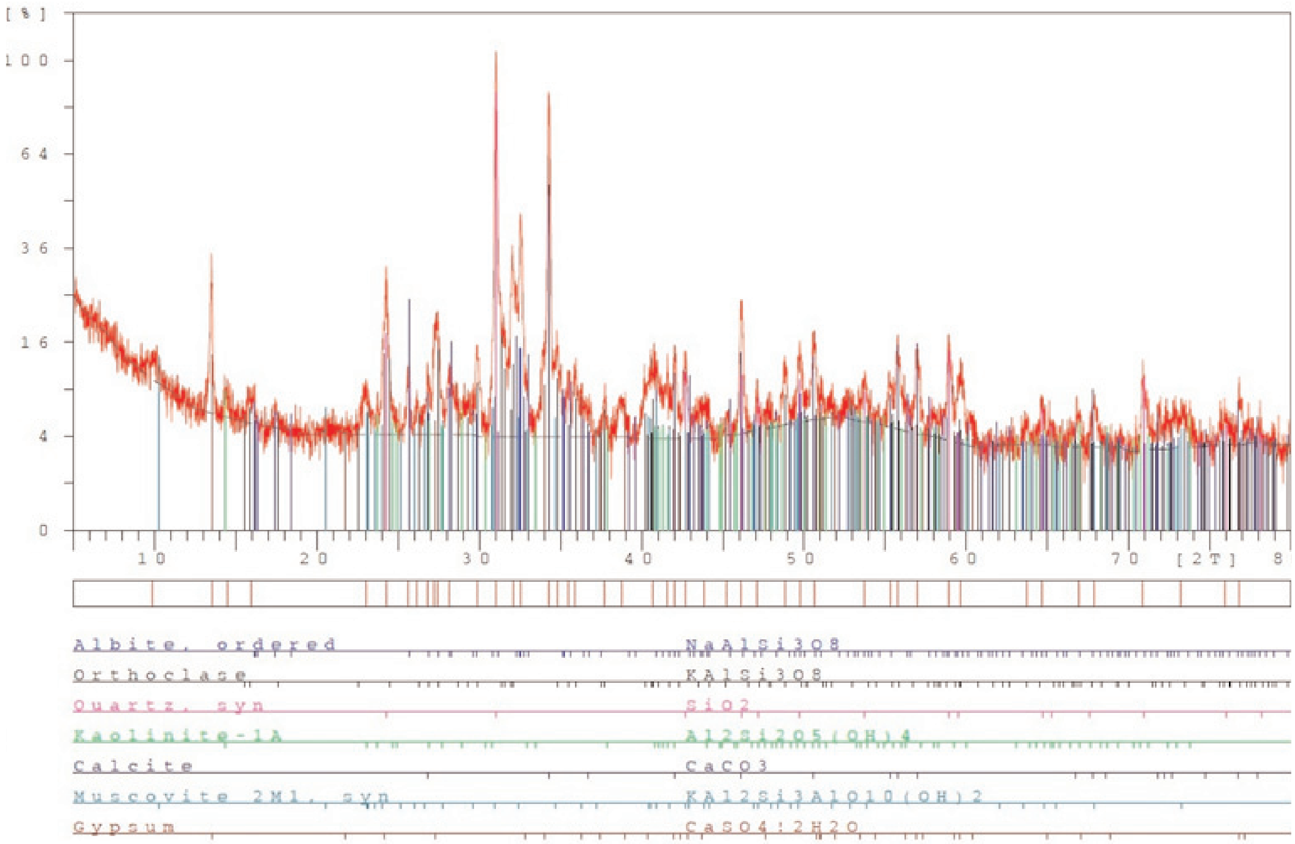


Figure 2. result of XRD test on studied clayey soil

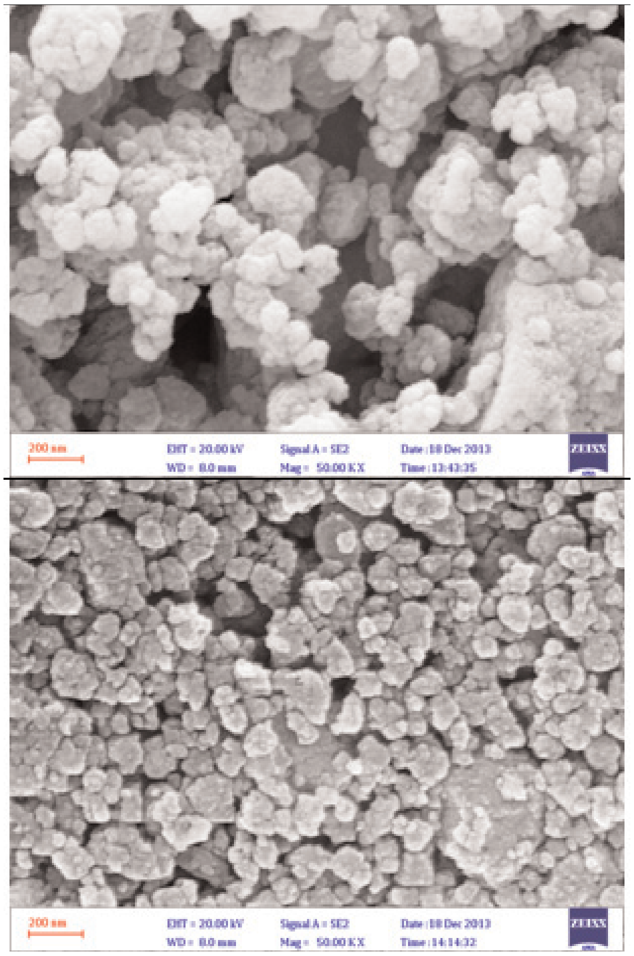


Figure 3. FESEM images of nanosilica (above) and nanokaolinite (below) powders.

Table 3. chemical composition of nanosilica and nanokaolinite by XRF test

Chemical composition	Nanopowders	
	nanosilica	Nanokaolinite
L.O.I	0.1	20.87
Mgo	1.076	0.343
Al2o3	0.422	31.228
Sio2	96.243	41.158
Cao	1.094	1.054
K2o	-	3.446
Traces	Na,P,S,Cl,Cu	F,Na,Ti,Mn,Ni

Table 4. optimum condition of Planetary Ball Mill performance for producing of nanoparticles

Parameter	Parameter Quantity
Speed of Rotaion	500 Rpm
Milling Time	10 Hours
Ball Size	10 number 10 mm 10 number 15 mm
Balls and cup type	Steel with 60 Rc hardness

nanoparticles is corresponding to optimum water content of soil resulted from compaction test.

First, for finding the optimum percentage addition of nanoparticles to soil, samples with 2 days preservation humidity were made for different dosage of nanoparticles (0.5, 1, 1.5, 2 and 2.5 % of dry soil weight). After this, in order to investigate the effect of preseervation humidity time, samples were made with 7, 14 and 28 days preservation humidity in addition to optimum dosage nanoparticles and then tests were done.

Figure 8 shows cohesion chainage with different dosage of nanoparticles for samples with 2 days preservation humidity that is obvious that 2 days samples with 1% nanokaolinite and 1.5% nanosilica possess maximum cohesion and this dosages are chosen as optimum dosages for doing of later tests.

Figure 8 shows that with addition to different dosages of nanokaolinite to 1% of dry soil weight and nanosilica to 1.5% of dry soil weight, the cohesion of soil increases and after optimum dosage, it decreases. But always soil with nanoparticles possesses more cohesion than unamended soil. Cohesion of original soil is 12 KPa that increase to 32 KPa by adding 1% nanokaolinite and 43 KPa by adding of 1.5% nanosilica.

Figure 9 shows the effect of preservation humidity days on cohesion of amended clayey soil with 1% nanokaolinite and 1.5%nanosilica.

Figure 9 shows that increasing of preservation humidity time to 14 days causes increasing the cohesion of amended soil and more than this period of time cannot make notable chaining in cohesion. Cohesion of amended soil with 1% nanokaolinite increases from 32 KPa in 2 days preservation humidity to 92 KPa in 14 days preservation humidity and the increase for 1.5% nanosilica addition is from 43 KPa to 120 KPa (i.e. almost 3 fold increase for both cases).

With regard to that direct shear test done by 74, 128 and 222 KPa forces in 3 steps, results showed that shear strength under mentioned forces increased by adding nanoparticles to optimum dosage and increasing of retained humidity time to 14 days due to

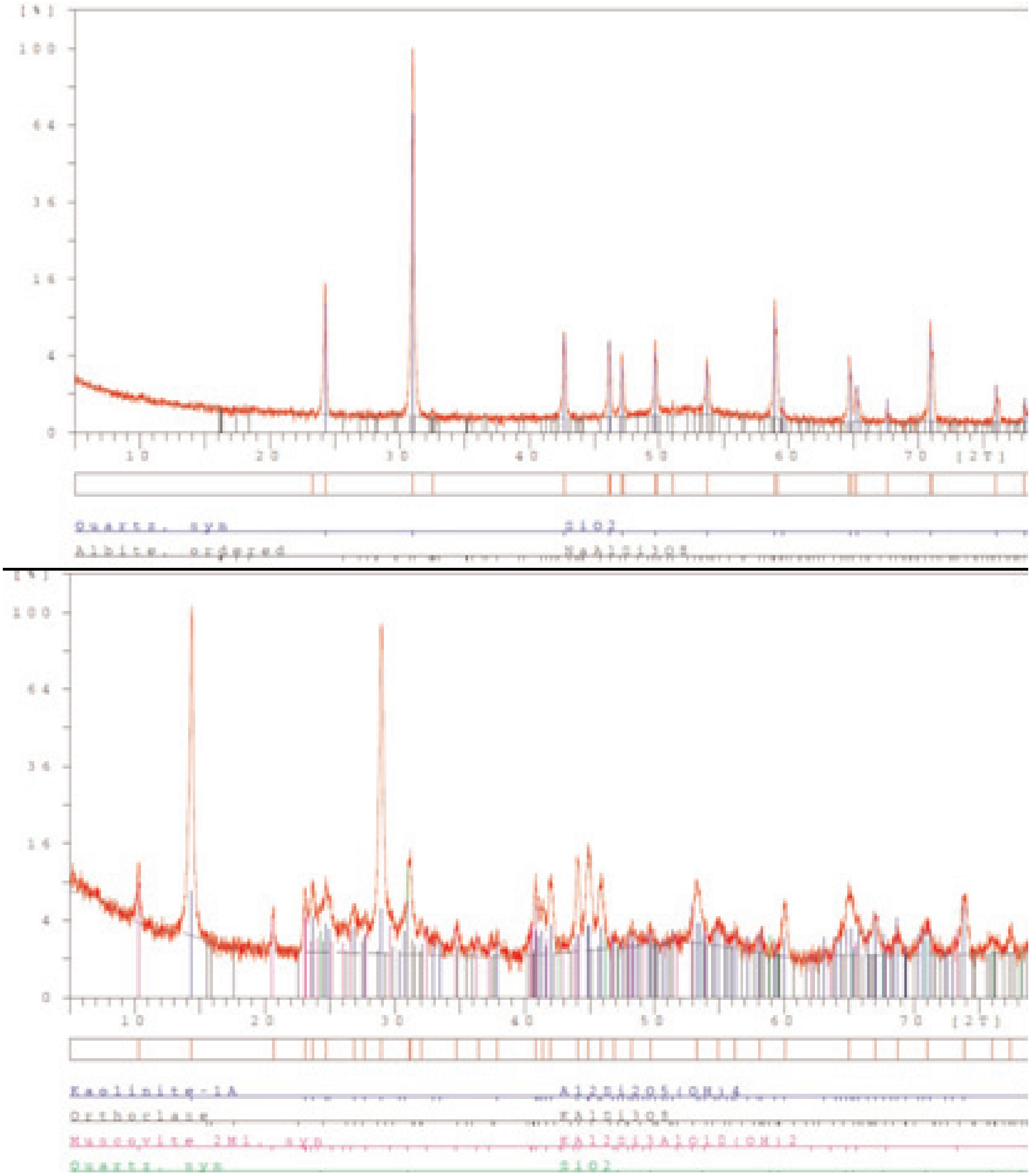


Figure 4. Result of XRD test on nanosilica (above) and nanokaolinite (below)

increasing of cohesion between soil particles. Friction angle of amended soil has not change during addition of nanoparticles corresponding to figure 10.

2.2.4 Compressive strength test based on ASTM D: 2166-00

Preparation of samples is similar to direct shear test. The only difference is in dimensions of cast and samples were dried 48 hours before testing.

First, for finding the optimum percent of adding nanoparticles to soil, samples with 2 days preservation humidity were made in addition to different dosage of nanoparticles (0.5, 1, 1.5, 2 and 2.5 % of dry soil weight). After this, in order to investigate the effect of preservation humidity time, samples were made with 7, 14 and 28 days preservation humidity in

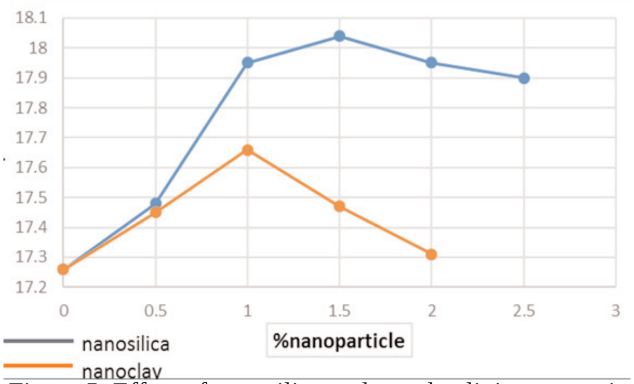


Figure 5. Effect of nanosilica and nanokaolinite on maximum dry density of CL soil

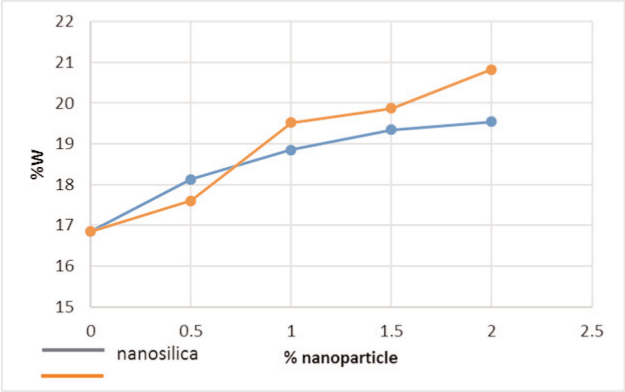


Figure 6. Effect of nanosilica and nanokaolinite optimum water content of CL soil

addition to optimum dosage nanoparticles and then tests were done.

Figure 11 shows cohesion chainage with different dosage of nanoparticles for samples with 2 days preservation humidity. It is obvious that 2 days samples with 1% nanokaolinite and 1.5% nanosilica possess maximum cohesion and the mentioned dosages are chosen as optimum dosages for doing later tests. Nanopartricle dosages with more than 1% nanokaolinite and 1.5% nanosilica cause agglomeration of nanoparticles, hence decreases volume density of soil sample. By adding 1% nanokaoilinite to CL soil composition, its USC reaches from 90 KPa of original soil to 130 KPa. Also, by adding 1.5% nanosilica to soil, unconfined strength increases to 160 KPa rather than 90 KPa in unamended form.

Figure 12 shows the effect of preservation humidity days on UCS of amended clayey soil with 1% nanokaolinite and 1.5%nanosilica.

Figure 12 shows that increase of preservation humidity time causes increase of compressive strength of amended soil to nearly 100%. UCS of amended soil

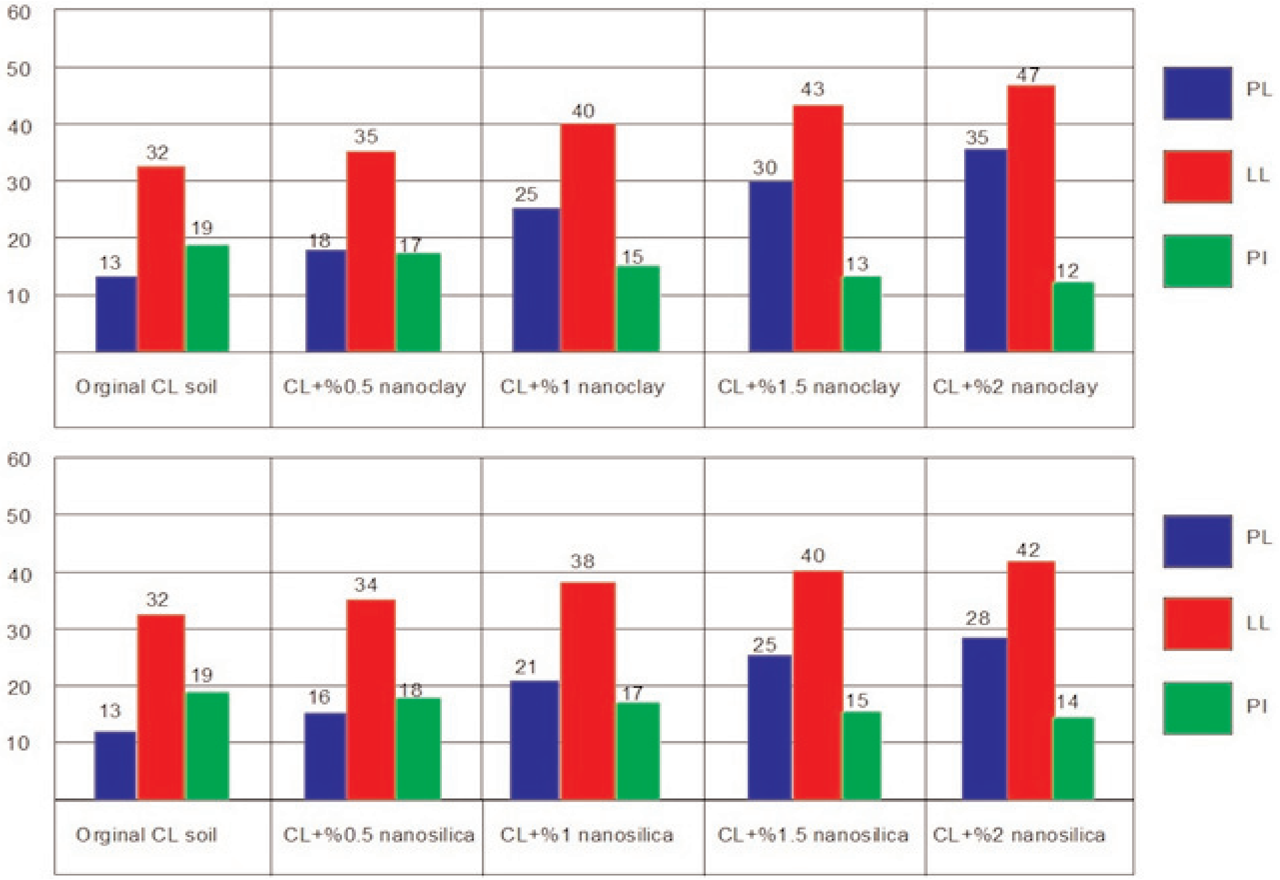


Figure 7. Effect of nanokaolinite (above) and nanosilica (below) on Atterberg limits of CL soil.

with 1% nanokaolinite increase from 130 KPa in 2 days retained humidity to 240 KPa in 28 days preservation humidity. Also, UCS of amended soil with 1.5% nanosilica increases from 160 KPa in 2 days preservation humidity to 285 KPa in 28 days retained humidity. Also compressive strength of amended soils with nanoparticles increase nearly 3 fold of unamended soil.

3. Results

The effect of adding nanokaolinite and nanosilica to soil engineering properties was investigated in this study and the following results were found:

- Results of standard compaction tests showed that addition of nanokaolinite to 1% and nanosilica to 1.5% weight of soil causes increase in density of CL soil. However, amended soils possess more density than unamended soil.
- Another standard compaction test which is increasing dosage of nanoparticles in soil composition causes increase of optimum humidity content of soil.
- Results of cassagrande tests showed that by

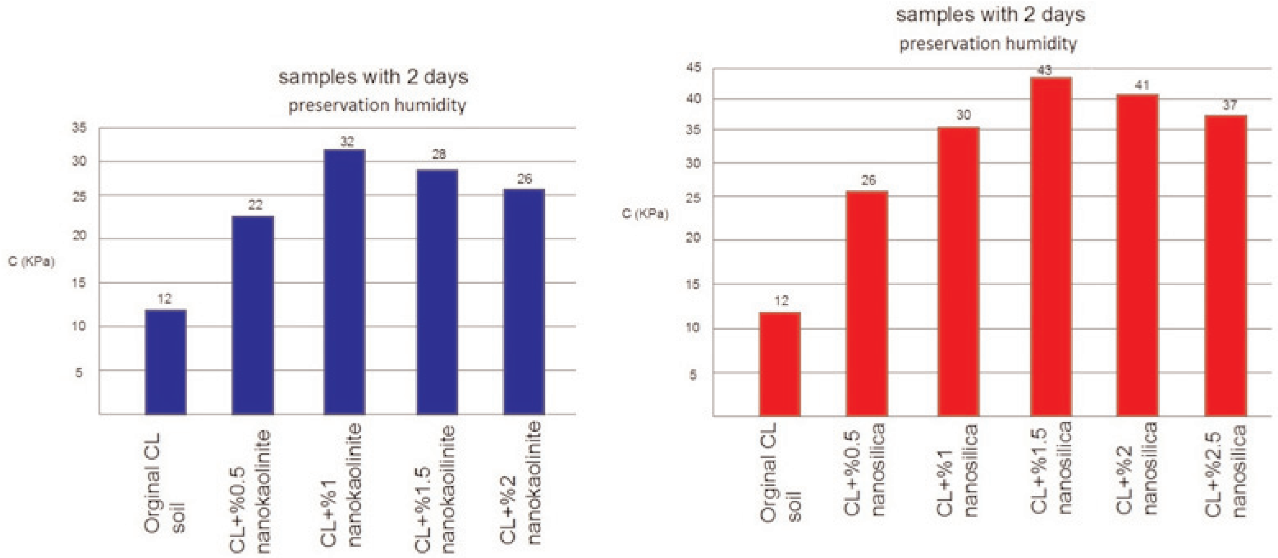


Figure 8. the effect of addition of different dosage of nanokaolinite (left side) and nanosilica (right side) on cohesion of CL soil in order to finding the optimum dosages of nanoparticles.

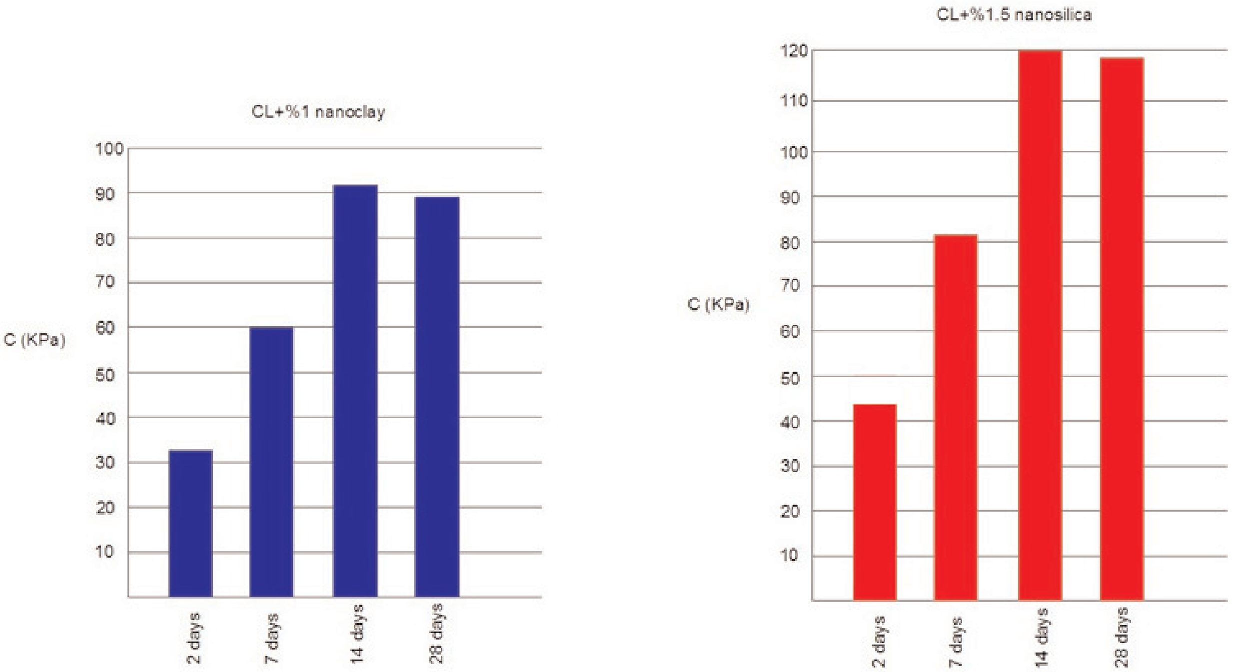


Figure 9. the effect of preservation humidity days on cohesion of amended clayey soil with 1% nanokaolinite (left side) and 1.5% nanosilica (right side).

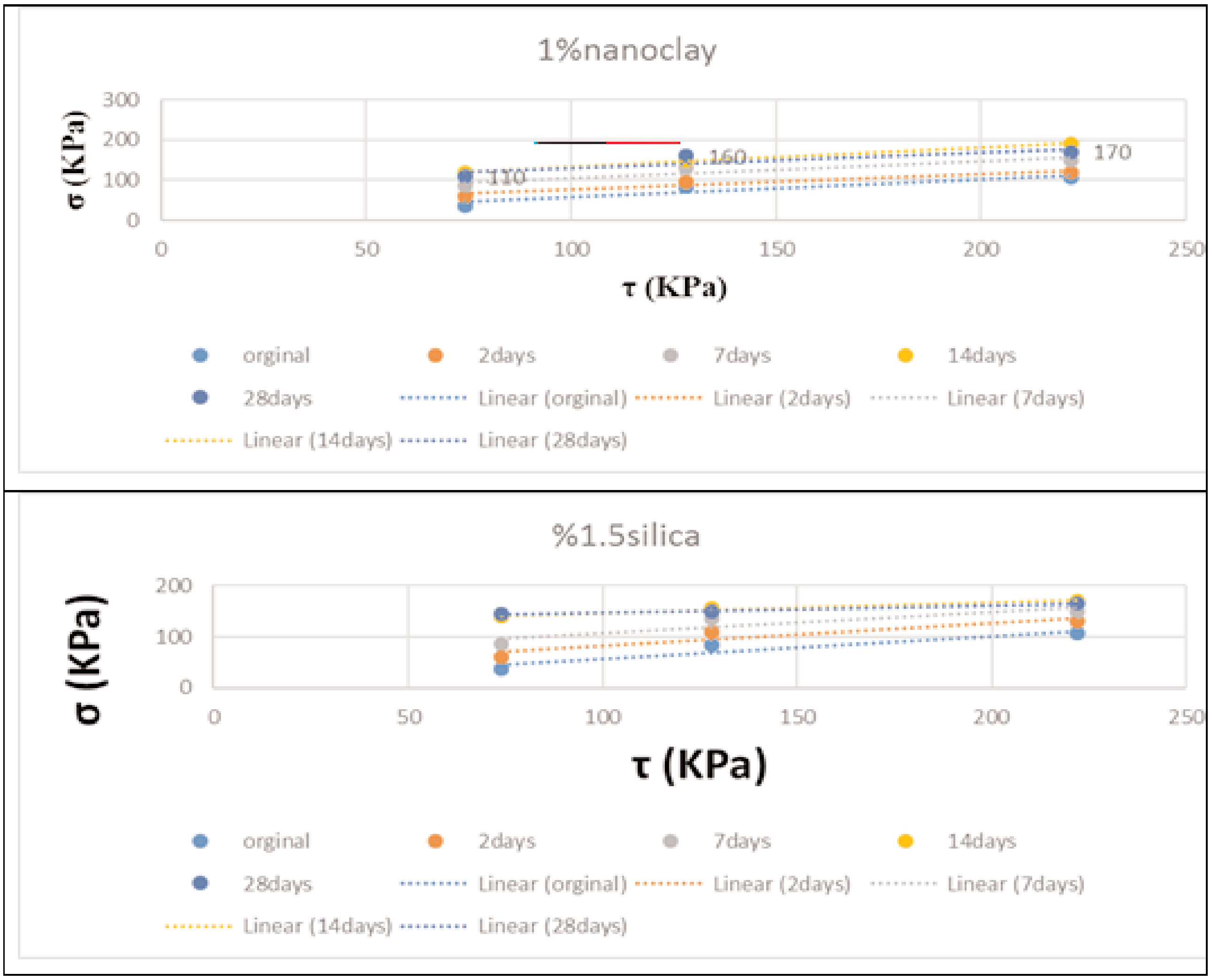


Figure 10. increasing of soil shear strength with addition of nanokaolinite (above) and nanosilica (low) to clayey soil and increasing of preservation days of humidity

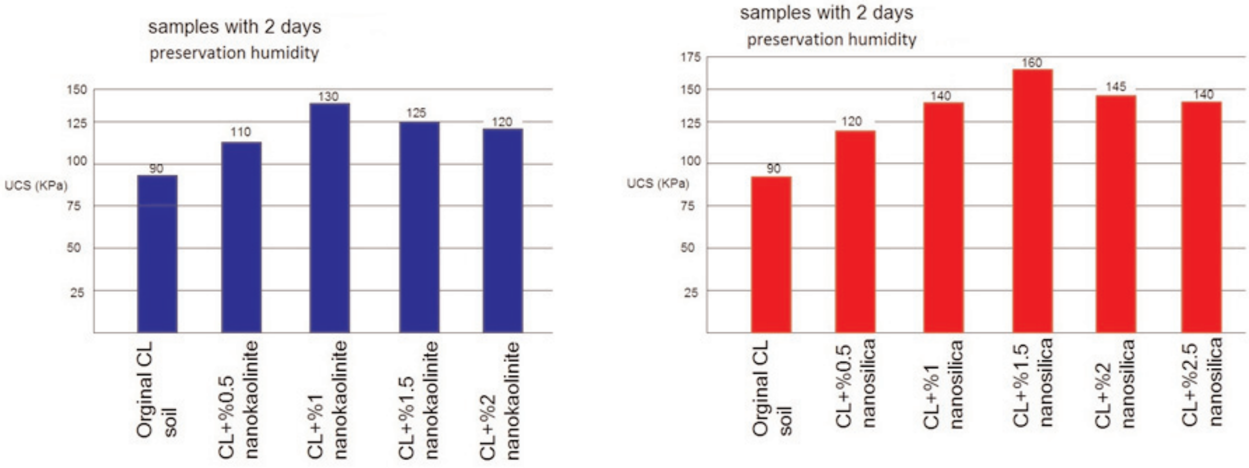
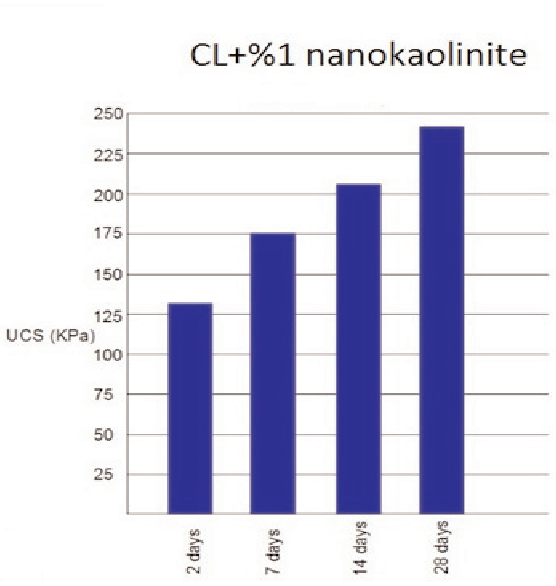


Figure 11. effect of nanokaolinite dosage (above) and nanosilica dosage (low) on clayey soil in order to finding of optimum dosages of addition.

increase of nanoparticle dosage in soil composition, liquid limit and plastic limit increased. Also Results showed that rate of increasing of plasticity limit (PL) is more than rate of increasing of liquidity limit (LL), thus Plastisity index (PI=LL-PL) is reduced when dosage of nanoparticle is increased.

- Results of shear strength tests showed that samples with 2 days preservation humidity and with 1%



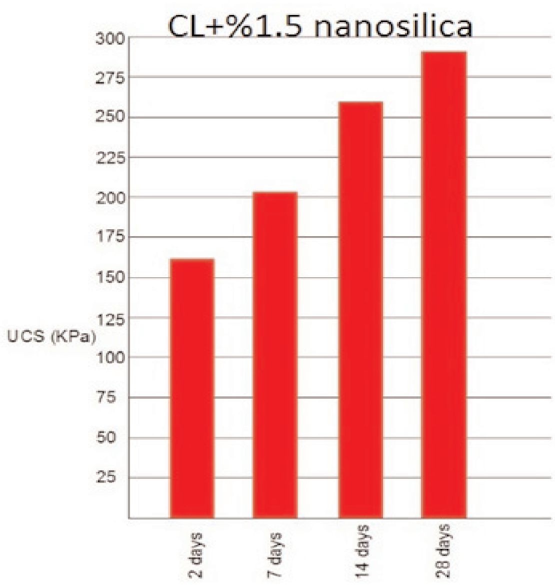


Figure 12. effect of preservation humidity days on chainage of compressive strength of samples possess 1% nanokaolinite (left) and 1.5% nanosilica (right)

nanokaolinite and 1.5% nanosilica possess maximum cohesion and these dosages are chosen as optimum dosages for preservation tests.

- Another result of shear strength tests showed that increasing preservation humidity time to 14 days causes increase in the cohesion of amended soil (nearly 3 fold) and more than this time does not make notable chaining in cohesion. Also, friction angle of amended soil has not changed during the step of adding the nanoparticles.
- Results of unconfined compression tests showed UCS changes with different dosage of nanoparticles for samples with 2 days preservation humidity. As it was observed, 2 days samples with 1% nanokaolinite and 1.5% nanosilica possess maximum UCS and this dosages are chosen as optimum dosages for doing later tests.
- Another result of unconfined compression tests showed that increasing preservation humidity time causes increase in compressive strength of amended soil to nearly 3 fold than unamended soil.
- Results of XRD and XRF tests showed that chemical composition of nanoparticles produced from planetary ball mill is similar to initial powder and is not changed.

References

ASTM D: 698-78.Standard test method for compactiontest in laboratory.

ASTM D: 4318-87. Standard test method for LiquidLimit, Plastic Limit and Plasticity Index of soils.

ASTM D: 3080-90. Standard test method for directshear test of soils.

ASTM D: 2166-00. Standard test method for unconfined strength of soil.

Burton C. 2009. Silica sol for rock grouting, laboratory testing of strength, fracture behavior and hydraulic conductivity.*Tunneling andUnderground Space Technology:* 603- 607.

Das M. B. 2010. *Principles of Geotechnical Engineering.* 7th Edtion. Cengage Learning.

Firoozi A. A., Taha M. R., Khan T. A. 2014.Assessment of Nano-Zeolite on Soil Properties. *Australian Journal of Basic and Applied Sciences,* 8(19), Special Issue,: 292-295.

Gallagher P.M., Conlee C.T., Rollins K.M. 2007.Full-Scale Field Testing of Colloidal SilicaGrouting for Mitigation of Liquefaction Risk. *ASCE*_1090-0241,133:2-186.

Gallagher P.M., Lin Y. 2005. Column Testing to Determine Colloid Silica Transport Mechanisms.

Sessions of the Geo-Frontiers Congress.

Kadivar M., Barkhordari K. (2011). Nanotechnology in Geotechnical Engineering. *Journal of Advanced Materials Research,* 261: 524-528.

MajeedZ.H., TahaM.R. 2011. Effect of nanomaterial-treatment on geotechnical properties of a Penang soil. *Journal of Asian Scientific Research:*587-592.

MajeedZ.H, Taha.M.R, Javad, I. T. 2014.Stabilization of soft soil using nanomaterials. *Research Journal of Applied Sciences, Engineerringand Technology,* 8(4): 503-509.

Michael F., Hochella Jr. 2002. Nanoscience and technology,the next revolution in the Earth sciences. *Blacksburg.*

NSTC 2007. The National Nanotechnology Initiative - Strategic Plan. *Executive Office of the President of theUnited States.*

Noll MR., Bartlett C., Dochat TM. 1992. In Situ Permeability Reduction and Chemical Fixation Using Colloidal Silica. *National Outdoor Action Conference, Las Vegas,* NV: 443-457.

Taha M.R. 2009. Geotechnical Properties of Soil-Ball Milled Soil Mixtures. *In: Proc of 3th International Symposium on Nanotechnology in Construction Prague.*

Thomas Paul K., Satpathy S., Manna I.,Chakraborty K., Nando G. 2007. Preparationand characterization of nanostructured materials fromfly ash: a waste from thermal power stations by highenergy ball milling.

TRS - The Royal Society 2004. Nanoscience and Nanotechnologies: Opportunities and Uncertainties. *RS Policy Document No. 19/04*.

Yonekura R., Miwa M. 1992. Fundamental Propertiesof Sodium Silicate Based Grout.

Zhang G. 2007. Soil Nanoparticles and Their Influenceon Engineering Properties of Soils. *Advances in measurementand modeling of soil behavior, ASCE.*

Zhang G., Germaine J. T., Whittle A. J., Ladd C.C. 2004a. Soil structure of a highly weathered oldalluvium. *Geotechnique,* 54(7): 453-466.

Zhang G., Germaine J. T., Whittle A. J., Ladd C. C.2004b. Index properties of a highly weathered oldalluvium. *Geotechnique,* 54(7): 441-451.