IRAQI Academic Scientific Journals

ISSN: 1813-162X (Print); 2312-7589 (Online)

Tikrit Journal of Engineering Sciences

available online at: http://www.tj-es.com

TJES Tikrit Journal of Engineering Sciences

Geotechnical Study of Expansive Soil Treated with Nano-Calcium Carbonate Materials in Al-Faw City, Southern Iraq

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Keywords:

Carbonate calcium; Expansive soil; Nano Carbonate Calcium (NCC); Soil stabilization; Unconfined compressive strength.

Highlights:

- *Stabilizing expansive soil to improve its engineering and classification properties.*
- *Determine the best-adding percentage of the treated material nano-calcium carbonate.*
- *Classification of Al-Faw soils using the Unified Standard Classification System (USCS).*

ARTICLE INFO

Article history:

Received	03 Sep. 2023
Received in revised form	06 Dec. 2023
Accepted	13 Jan. 2024
Final Proofreading	05 July 2024
Available online	20 Mar. 2025

Citation: Abdulamer HN, Daham HA. **Geotechnical Study of Expansive Soil Treated with Nano-Calcium Carbonate Materials in Al-Faw City, Southern Iraq**. *Tikrit Journal of Engineering Sciences* 2025; **32**(1): 1615.
http://doi.org/10.25130/tjes.32.1.14

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Abstract: Soil stabilization with tiny particles is a newly investigated topic that has mostly been studied in the laboratory and requires additional investigation before it can be applied in the field. The present study studies nano-calcium carbonate, an almost unknown nanomaterial addition for swelling soil stability. The study ascertains the ideal proportion of nano-calcium carbonate to improve soil. Soil samples were divided into three groups. The first group only mixed genuine soil with 4% lime, the second group mixed only natural soil with different percentages of nano-calcium carbonate (0.3%, 0.7%, 1.1%, and 1.5%), the third group was outfitted by changing the percentages of nano-calcium carbonate, i.e., 0.3%, 0.7%, 1.1%, and 1.5%, added to the mixture (soil plus 4% lime). Several tests were performed on this mixture, with all samples exposed to time for cure at 1, 7, and 28 days. The results showed an improvement in the Atterberg's limits, as they decreased with increasing the percentage of lime and nano-calcium carbonate addition. It also showed an improvement in the unconfined Compression Strength (UCS). The ideal dosage for improving UCS was 0.7% nano-calcium carbonate and lime addition, which generated a UCS at 28 days of curing, nearly five times more than untreated soil.

دراسة جيوتقنية للتربة المتمددة المعالجة بمواد كربونات الكالسيوم النانوية في مدينة الفاو، جنوب العراق

حنين ناظم عبد الامير، هدى احمد دحام
قسم الجيولوجيا/ كلية العلوم / جامعة البصرة / البصرة – العراق.

الخلاصة
يعد تثبيت التربة باستخدام الجسيمات النانوية موضوعًا بحثيًا حديثا، تم بحثه في الغالب في المختبر حتى الان، وبالتالي يتطلب دراسة اضافية قبل تطبيقه في الميدان. تعزز الدراسة الحالية استخدام كاربونات الكالسيوم النانوية، وهي مادة مضافة غير معروفة نسبيًا للمواد النانوية، تعمل على تثبيت التربة الانتفاخية. يهدف هذا البحث الى تحديد أفضل نسبة من كربونات الكالسيوم النانوية لتحسين التربة. تم استخدام ثلاث مجموعات من عينات التربة، المجموعة الأولى من العينات خليط تربة طبيعية مع ٤٪ من النورة فقط، أما المجموعة الثانية فخليط تربة طبيعية مع نسب مختلفة (٠,٣٪، ٠,٧٪، ١,١٪ و١,٥٪) من كاربونات الكالسيوم النانوية فقط، والمجموعة الثالثة تم تحضيرها بخلط (التربة +٤٪ من النورة) مع نسب مختلفة (٠,٣٪، ٠,٧٪، ١,١٪ و١,٥٪) من كربونات الكالسيوم النانوية. تم اجراء عدد من الاختبارات على هذا الخليط مع تعريض جميع العينات لفترات معالجة (١، ٧و ٢٨) يوم. أظهرت النتائج تحسنا في حدود أتربرغ إذ انها تنخفض مع زيادة النسبة المئوية لإضافة النورة وكربونات الكالسيوم النانوية، كما أظهرت تحسنا في مقاومة الضغط غير المحصور (UCS) وتم العثور على الجرعة المثالية لتحسين (UCS) بإضافة ٠,٧٪ من كربونات الكالسيوم النانوية والنورة، مما أدى الى توليد (UCS) ما يقرب خمس مرات أكثر من التربة غير المعالجة في ٢٨ يوم.

الكلمات الدالة: تثبيت التربة، تربة منتفخة، كاربونات الكالسيوم، كاربونات الكالسيوم النانوية، مقاومة الانضغاط غير المحصور.

1.INTRODUCTION

Expansive soils are widespread worldwide, especially, in the arid and semi-arid regions. These soils are considered very dangerous to engineering structures when built upon, due to their tendency to swell and shrink during wet - dry seasons [1-4]. The study area has a flat terrain consisting mainly of clay and silt deposited by the Tigris, Euphrates and Karun rivers [5]. The importance of quaternary deposits lies in being the foundation on which the shallow and deep foundations of engineering structures rest [6]. These deposits are dominated by minerals chlorite, illite, kaolinite and silica [7]. Mahmood and Daham [8]. The swell qualities chosen for Al-Faw soils on the surface were studied. It was determined that the soils in this region are silty clay or clayey silt, with swelling effort ranging from medium to extremely high, negatively affecting the strength of the city's engineering infrastructure. Daham and Hadadi [9] concluded that the higher the groundwater level and the substantial quantity of sodium salts found, weaker the soil and the higher its depressiveness, causing the structures built on it to collapse. Soil improvement technologies have been extensively applied to enhance the geotechnical properties of low-strength soils that do not meet building requirements, particularly regarding capacity for bearing. General ground improvement techniques used to reduce swelling issues include chemical additive stabilization, squeezing, overloading, and water content avoiding them [10]. Chemical and mechanical methods of modifying and improving have been around for decades. Raising the value of internal friction and soil density changes the soil's texture mechanic and improves its mechanical strength. Chemical stabilization modifies the soil properties by improving the connection between soil components. As a result, soil development incorporates diverse ingredients, such as cement, lime, polymer compounds, bitumen, emulsions, and reused resources [11-15]. In geotechnical engineering, nanotechnology is a new approach. Including of nanoparticles can alter the soil properties, emphasizing the possibility of their usage in soil stabilization. Due to their low cost, rapidity, and environmental friendliness, nanomaterials have increased enormously in demand in the past few years [16]. Majeed et al. [17] added various nanomaterials to the soft clay. The study indicated enhancements in the unconfined compressive strength, linear shrinkage, plasticity index, and maximum dry density. It was concluded that adding fine particles such as nanomaterials, can enhance and improve soil properties even in low doses.

Regular magnesium oxide (R-MgO) and nano magnesium oxide (N-MgO) were used by Taha et al. [18]. At 1 and 28 days of curing, the greatest percentages of the plastic limit were 21.8% and 24.7% for 1.0% (N-MgO)., The minimal liquid limit values for the 0.3% (N-MgO) admixture reached 27.3% and 26% for the first and 28 days of cure, respectively. Despite this, the (N-MgO) significantly impacted on lowering the treated soil's plasticity index values. Alsharef et al. [19] clarified the impact of two forms of nanocarbons on compaction characteristics: multiwall carbon nanotubes and carbon nanofiber. Since nanocarbons tend to fill the voids in the soil skeleton and the optimal moisture content drops, as a result, they concluded that there is a relationship between employing the ideal ratio of nanomaterials and raising the optimum water content. Additionally, because nanomaterials have a higher particle density than natural soil, treated soil significantly increased dry density. Naval et al. [20] examined how to improve Singapore's swelling soil using nanomaterials. The study indicated the possibility of reducing swelling in the soil when adding nanomaterials thus making the soil suitable for construction.

Kannan et al. [21] pointed out that the UCS of the treatment's poorly sand-compacted soil compared to untreated soil showed the ideal dosage of 0.4% nano-calcium carbonate , with a 55% UCS increase obtained within two hours of combining the components, as well as a 194% UCS improvement organized for 90 days of curing. From the beginning, gains in strength were accomplished using void filling, with greater strength acquired after additional curing due to weakened crystalline CSH gel formation. The present study focuses on nanomaterials, because few studies have been conducted on improving expansive soil with these materials. Thus, this study presents the findings of scientific testing to clarify the effects of employing nano-calcium carbonate on improving certain swelling soil geotechnical properties.

2.LOCATION OF SOIL SAMPLE COLLECTION

The study region is in Iraq's southeast. Sixteen locations in Basrah were chosen in Faw City between longitudes (48.117180 and 48.519784) east and latitudes (29.868122 and 30.268181). The climate of Al-Faw City is cold and humid in the winter and hot and dry in the summer, high percentage of solar radiation, lack of rain, and high humidity compared to the rest of the country due to its nearness to bodies of water and the northern and northwest coasts of the Arabian Gulf [22].

3.MATERIALS AND PROCEDURES

3.1.Field Work

To comprehend soil behavior and choose the most suitable areas for this study, fieldwork was performed in Al-Faw in November 2023.

3.1.1.Sampling

To recognize their classification properties and determine the type of soil, samples used in this study were taken from sixteen sites at a depth of about 1.5-2.0m below the surface of Al-Faw City.

3.1.2.Soil

The soil used for this study was from Al-Faw city, in southern Iraq. Table 1 displays the soil's physical properties.

3.2.Additives to the Soil

a) Lime: Selected 4% of the hydrated lime, found according to the method of Ref. [23], was added based on the weight of the dry soil, where the lime blends well inside the sealed plastic packaging. Then the water was gradually added to the mix and left for an hour from the beginning of adding water. Table 2 summarizes the chemical composition of the lime used in the research.

b) Nano-calcium carbonate: Nanoparticles have been used in certain amounts as a substitute for lime to improve the lime reaction efficiency. The soil was treated with 0.3%, 0.7%, 1%, and 1.5% nano-calcium carbonate. The tested soil was dried in an oven before being modified. The nano-calcium carbonate material was then separated into small quantities. To obtain the desired weight (based on dry soil mass), the required dosage was added. Small amounts were then blended and thoroughly mixed to guarantee homogeneity. Table 3 lists the NCC material properties.

c) Four percent of the dry soil weight was applied as lime. As a replacement material for lime, the percentages of CaCo3-Nano material were 0.3%, 0.5%, 1.1%, and 1.5%. After mixing the lime and nanoparticles in a particular ratio, the mixture was added to the soil and mixed using the water mixer next to it.

3.3.Characterization of Materials

The soil sampled was silty clay, which the United Soil Classification System (USCS) categorized as Clay high plasticity (CH). The soil comprised 64% clay, 35% silt, and 1% sand. Table 1 lists several geotechnical properties of the test soil. The natural water content of the soil examined was 16%, the liquid limit was 63%, the plasticity index was 31%, the activity was 0.48, the maximum dry density was 17.2 kN/m^3, the optimal moisture content was 17%, and the unconfined compressive strength was 26 kN/m^2, Table 3.

Table 1 The Studied Soil Properties.

Properties	Standard Specifications	Values
Clay%	ASTM D7928-21e1	64%
Silt%	ASTM D7928-21e1	35%
Sand	ASTM D7928-21e1	1
Liquid limit	ASTM,D4318 – 17	63%
Plastic limit	ASTM,D4318 – 17	32%
Plasticity index	ASTM,D4318 – 17	31%
Swelling Potential	-	High
Shrinkage limit	ASTM,D4318 – 17	32%
Maximum dry density kN/m^3	ASTM D698-12	17.2
Optimal moisture content	ASTM D698-12	17%
Natural water content	ASTM D2216-05	16%
Unconfined compressive strength kN/m^2	ASTM D2166/D2166M-16	26
Organic matter	BS.1377: 1990	2.93%
SO_3	BS. 1377: 1990	0.22%
Chloride	BS.1377: 1990	0.71%
CaCO3	BS.1377:1990	9.7%

Table 2 The Chemical Composition of the Used Lime.

Properties	Standard specifications	Values
$CaCo_3$ %	BS.1377:1990	6.2
Cao%	BS.1377:1990	6.1
$Ca(OH)_2$	BS.1377:1990	74.09
SiO_2	BS.1377:1990	11.1
Al_2O_3	BS.1377:1990	0.17
H_2O	ASTM E203	0.09

Table 3 The Nano Calcium Carbonate Material Properties Used in the Study.

Properties	Standard specifications	Values
Average grain size (nm)	ASTM C775-79	15-40
Color	-	White
Whiteness	ASTM 313-2020	93%
pH	BS.1377:1990	6-8
Specific Surface Area(m^2/g)	ASTM C1069	40
$CaCo_3$	BS.1377:1990	>97.5%
MgO	BS.1377:1990	<0.9
Fe	BS.1377:1990	<0.1%
Morphology	-	Cubic

3.4.Laboratory Test

3.4.1.Grain Size Distribution

The test determined the grain size by wet sieving to separate the grains of gravel and sand from the silt and clay and then using a hydrometer. The College of Sciences' Department of Geology examined soil samples while following the approach for particle size analysis described in [24].

3.4.2.Atterberg's Limits

Sieving the soil via sieve number forty (0.425 mm) was the first step in determining Atterberg's limits. The liquid limit was continuously checked first as a general guideline. A total of 25 drops were required to fill a 13-mm piece of groove carved into the soil sample, which was the liquid limit on one side, when the soil transitioned from a plastic to a liquid form. The percentage of water at the transition between the semi-solid and plastic states, on the other hand, was the plastic limit. The plastic limit was calculated using a gravimetric water content, in which a hand-rolled thread of soil with a 3 mm diameter may be formed without breaking. The plasticity index for each dosage was calculated using the liquid and plastic limit test results [25]. The Atterberg's limits tests were conducted at the Geological Laboratory, College of Science, Basra University.

3.4.3.Proctor Compaction Test

The test process involves mixing soil with various amounts of water before compacting. The standard Proctor test was used to estimate the highest dry density and the optimal moisture amount [26]. The compaction testing conducted in the College of Science Department of Geology.

3.4.4.Unconfined Compression Test

The main objective of this test is to assess unconfined compressive strength. Unconfined compressive strengths are the level of stress where an unconfined cylinder specimen of soil breaks in a sample compression test. In a sample compression test, the compressive stress where an unconfined cylinder specimen of soil fractures is known as the unconfined compressive strength. The greatest load attained per unit area is determined by this test method using unconfined compressive strength. This procedure is performed in the Uniaxial compression machine with [27], and the National Center for Construction Laboratories (Basrah Laboratory) examined the samples.

4.RESULTS AND DISCUSSION

4.1.Grain Size Distribution

Using the unified standard classification of soil (USCS), Figs. 1, the grain size analysis results were used to identify Al-Faw soil. Al-Faw soil has three types of soil: silty clay with low plasticity (CL), silty clay with high plasticity (CH), and clayey silt with low plasticity (ML). The change in sedimentary facies during the region's recent sedimentary history clearly impacted the soil type. The region has experienced many sedimentary environments due to the periodic fluctuation of the Earth's surface level, climatic changes, and tectonic activity. The southern section of the Mesopotamian Plain, including Al-Faw city, was covered in Holocene sediments, i.e., delta, river, and marine deposits almost identical to present conditions [28]. Clay percent significantly affected the engineering behavior of the soil, reducing soil permeability and increasing water mobility due to the capillary characteristic [29], as well as increasing the soil's compression and susceptibility to impulse, or the so-called swelling phenomenon. Clay soils were the most affected by swelling and shrinkage [30]. The clay compressibility was moderate and required careful regulation of water content. If the water is close to the foundations, it will run through the cracks and gather at the base, resulting in losing the soil much of its bearing capacity.

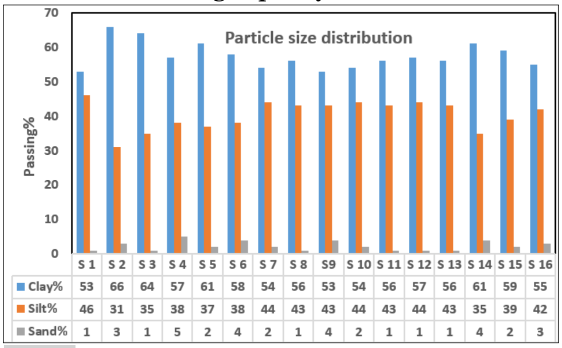


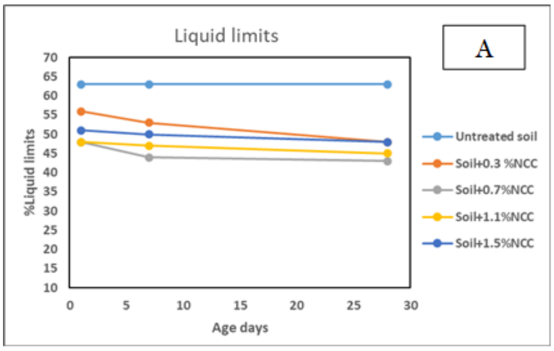
Fig. 1 Particle Size Distribution of Study Area.

4.2.Atterberg's Limits

The swelling soil engineering properties were tested. Figs. 2 and 3 display the results after the test results were examined. The liquid limit and plasticity index decreased; however, the plastic limit increased with the proportion of added lime and nano-calcium carbonate. Numerous studies indicated that the soil type may impact the treated soil's drop in liquid limit [31]. The aversion to water at the clay surface may be connected to the reduction in the treated soil's liquid limit. Water absorption when the added material contacts the soil generally causes the treated soil's plastic limit to rise. The results indicated a decrease in these limits and the possibility of increasing soil strength when increasing the nanomaterial content. Soil enhancement was motivated by decreasing the plasticity index. Thus, the reduction in plasticity index indicated that the soil enhanced when the nanomaterials were added to the natural soil even at in small amount [32]. The inference that may be drawn is that the particles of nano-calcium carbonate materials occupy the tiny openings in the mineral, obstructing the passage of water and minimizing soil swelling.

4.3.Proctor Compaction Test

This test is used to determine the effects of lime and nano-calcium carbonate on the maximum dry density and ideal moisture content measurements for soil samples. Figures 4-6 show the test results. It is clear that adding lime alone decreased the OMC% and lowered the maximum dry density. Also, the percentage of dry density can be changed by changing the applied proportion of nano-calcium carbonate. The results showed that the untreated soil had a maximum dry density value of 17.2 kN/m^3. After being treated with nano-calcium carbonate, it decreased to 16.6 kN/m^3, 16.7 kN/m^3, 15.58 kN/m^3, and 15.3 kN/m^3 by adding nanoparticles at concentrations of 0.3%, 0.7%, 1.1, and 1.5%, respectively, for one day cure. The optimal moisture content of the untreated soil was 17% and ranged from 15% to 14.2% when treated with 0.3% and 1.5% nano-calcium carbonate. When nano-calcium carbonate was used with lime, the MDD decreased compared to the sample soil with only 4% lime. Increased NCC and NCC replaced with 4% lime content reduced MDD and OMC. The ability of nanomaterials to absorb water from the soil has been correlated with a decrease in water content. Furthermore, when the nanoparticles were added to the soil, the ideal moisture content dropped due to the substantial surface area of the powdery nanomaterials. These outcomes were compared with those of Tarsh et al. [33] and Taha and Taha [34]. Furthermore, according to Bowles [35], a decrease in the volume of pores in the soil structure dropped the moisture content.



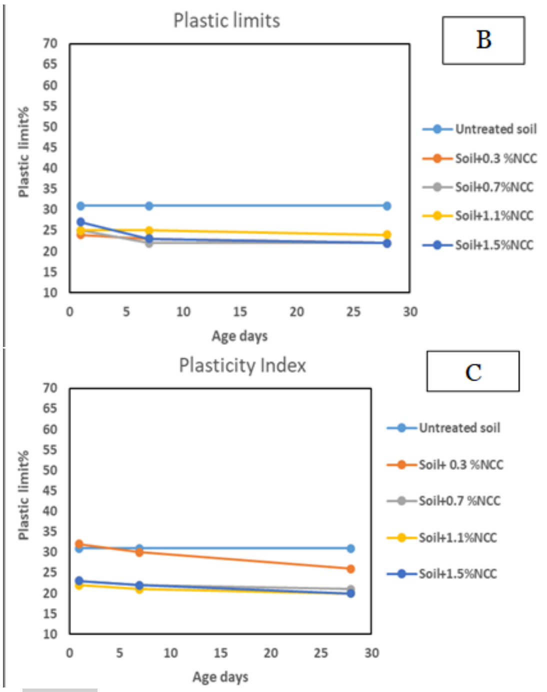


Fig. 2 (A, B, and C) Variation of Atterberg's Limits of Soil Treated with NCC%.

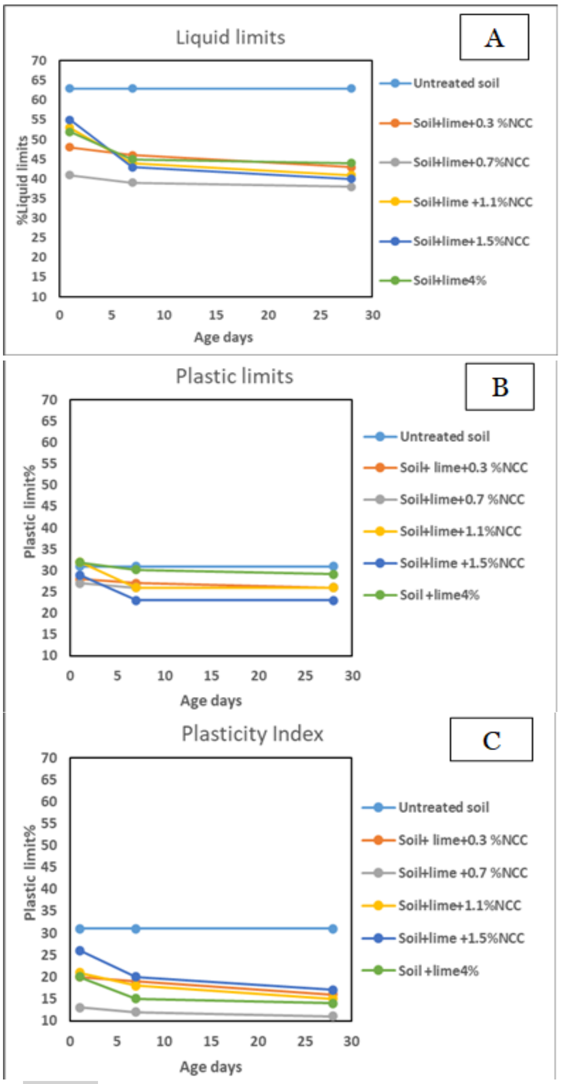


Fig. 3 (A, B, and C) Variation of Atterberg's limits of soil treated with NCC% and lime4%.

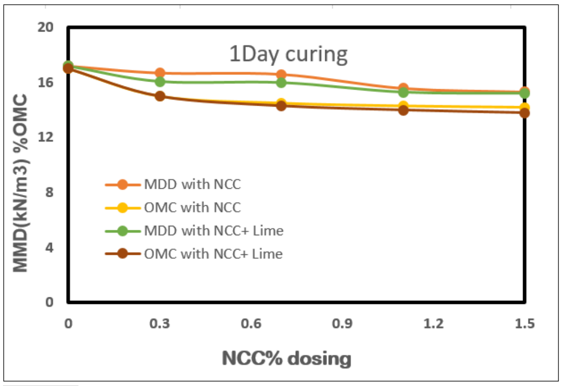


Fig. 4 MDD and OMC variations in untreated, Nano-calcium carbonate, and 4%lime-treated soil for 1-day curing.

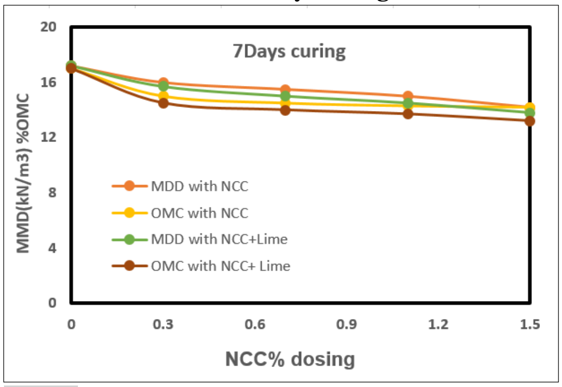


Fig. 5 MDD and OMC variations in untreated, Nano-calcium carbonate, and 4%lime-treated soil for 7 days-curing.

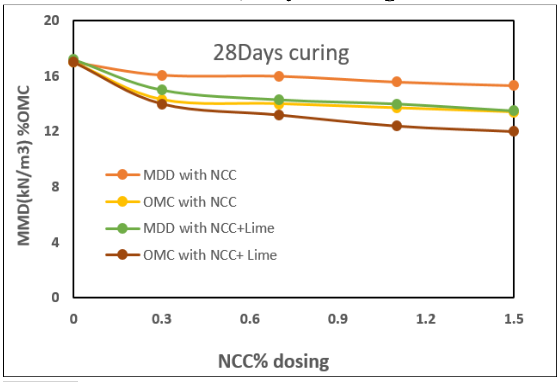


Fig. 6 MDD and OMC variations in untreated, Nano-calcium carbonate, and lime-treated soil for 28 days curing.

4.4.Unconfined Compression Strength (UCS)

Fig. 7 and 8 demonstrate the consequences of substituting nano-calcium carbonate for lime. As observed, USC increased when lime was substituted for nano-calcium carbonate by 0.3%, 0.7%, 1.1%, and 1.5%. The reduction was because the nano-calcium carbonate has a sizable area of interaction, which expands the pozzolanic reaction's area. Adding lime may have enhanced the pozzolanic process, as evidenced by the increased strength of the gypseous samples treated with lime [36]. Therefore, there are a lot of pozzolanic products. The highest amount was produced while the soil was amended with lime and 0.7% nano-calcium carbonate, and the compressive strength increased with curing time [37]. In general, calcium carbonate's reactivity increases as its particle size decreases to the nanoscale. This increase in nano-calcium carbonate reactivity encourages connections to soil clay minerals. It is essential to recognize that the increase in the soil's void ratio results in a conglomerate of nanomaterial particles in the soil matrix when the amount of nanomaterials reaches the ideal limit., so there will be less soil cohesion. Because the contact area between the soil and the additives increases with longer curing times, soil adherence to the addictive material may further develop. In adhesion will improve the soil cohesion [38, 39]. Based on these findings, it can be concluded that adding 0.7% nano-calcium carbonate to the soils can be considered an optimum mix for design purposes to improve the soil since it provides a maximum cohesion value when added to the soil.

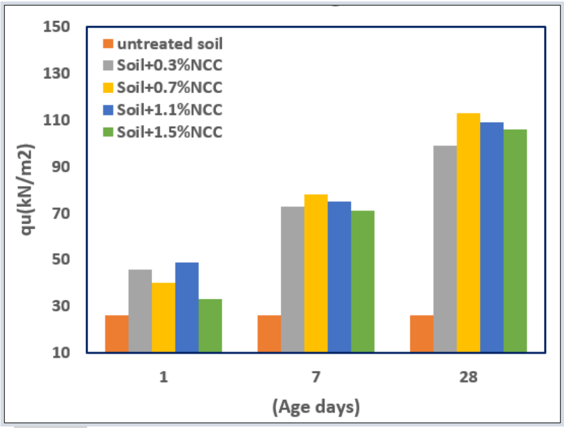


Fig. 7 Nano-Calcium Carbonate Treated Soil Compressive Strength Varies with Time.

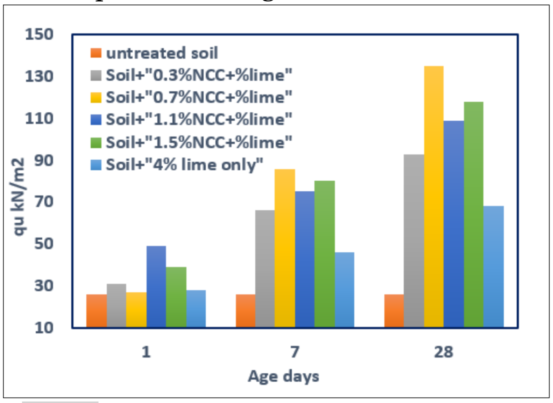


Fig. 8 Nano-Calcium Carbonate and Lime-Treated Soil Compressive Strength Varies with Time.

Based on the agreement with previous studies, the results and conclusion drawn above found that nano-calcium carbonate material significantly impacted soil behavior. This effect may be attributed to the fact that adding nanomaterial can modify soil properties, implying the potential for its application in soil stabilization. The interesting features of these materials stem from the great number of atoms and molecules at their free surface and the effects on their surface properties from physical, chemical and reactivity perspectives. Due to nanoparticles' high surface area and surface charge, even small amounts of these additives can make noticeable improvements in soil behavior.

5.CONCLUSIONS

- The values of the liquid limit and plasticity index gradually decreased with the percentages of lime and nano-calcium carbonate addition, indicating an improvement in swelling soil.
- The optimum moisture content (OMC%) decreased with increasing adding lime and nano-calcium carbonate
- In lime with nano-calcium carbonate stabilized soil specimens by 0.7%, the amount of curing time significantly impacted the unconfined compressive strength; after up to 28 days of curing, the unconfined compressive strength was significantly improved.
- In light of the findings above, it is possible conclude that using nano-calcium carbonate treatment as a sustainable and environmentally beneficial material holds the potential for improving swelling soil behavior.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the Head of the Geology Department at Basrah University for his assistance. Postgraduate Research Grant (PGRG) No. (1655-7-3)/ Date:27/July/2021.

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