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Behavior of clayey soil treated with nano magnesium oxide material

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Article

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Consolidation characteristics

Abstract

Clayey soils are spread in many countries and require significant improvement. Recently, nanomaterial have been entered to the geotechnical research as a treatment material. Current study utilized magnesium oxide (MgO) as an additive to enhance swelling potential, compressibility characteristics, and index properties of clayey soil from Mosul city using different content of nano-MgO and under varies curing periods. The results showed that the free swell and swell pressure of the soil specimens have been reduced by 25%, and 19%, respectively for 0.25, and 0.75% content of nano material under 3 days of curing time at 25C. Results also showed that the compressibility characteristic represented by the compression index parameter has been reduced by 20.3% for 0.75% of nano-MgO material. Moreover, the soil plasticity index exhibited a maximum increase at 0.75% of nano content. Moreover, results showed that the *pH* value increased while the electrical conductivity (*EC*) decreased with the nano-MgO content. To evaluate the curing time effect, specimens were cured for varies curing time under curing temperature of 25 ºC. Then, the free swell, swell pressure, compression index, and Atterberg limits were measured. The results revealed that the free swell and swell pressure for both untreated and treated specimens were reduced during different periods of curing time. Furthermore, the compression index of treated soil was reduced by approximately half for curing time of 28 days. In sum, the swelling and consolidation reduction with curing brought significant improvement and promising results for the treated samples.

1. Introduction

Soils provide the base that any construction will rest on for the entire design lifetime, some of which are weak or cannot withstand the weights or may cause future problems for the superstructure. Clayey soil is one of them that is affected by the presence of moisture and may show swelling potential or low strength upon wetting. This behavior is related directly to the phenomena of diffused double layer (DDL) which depends on clay mineralogy and the negative charges located on the surface of the clay minerals (Meshram et al., 2021).

For decades, many additives were used to mitigate the negative impacts of clayey soil on the structures, for instant lime, multi-part polymeric chemical admixture, calcium carbide residual-coal fly ash, cement, cement kiln dust, coal fly ash, ground granulated blast furnace slag-magnesium oxide, lime-cement, lime-natural pozzolans, calcium sulfate-furnace cement (Starcher et al., 2018), and many other different additives. Starcher et al. (2018) used the multi-part polymeric chemical admixture to treat low plasticity clayey soil (CL) in order to increase the strength of the soil that may use for low-cost unpaved roads construction, and to increase the durability of the soil by reducing the volume changes upon wetting-drying cycles.

However, many of these additives, which are used to modified clayey soil, have some negative impact on the project itself or even on the environment. Some of these impacts are represented by the cost and the carbon emissions during the production of these materials. For example, the cost of cement and the carbon footprint of its production process rise some concern about using it as an additive to treat soils. Also, the toxicity of some additives affects their uses as a modifier for soils (Pusadkar et al., 2017), especially when high amount is needed to reach the required enhancement in the engineering properties, or when the soil modification encounter with water table fluctuation. Due to all of that, engineers have started searching for alternative additives that are cheap, can be used with very low amount to reach the required engineering properties, and eco-friendly, all of these characteristics are available in nanomaterials.

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Nanomaterials or specifically "Nanotechnology" was first mentioned by Richard Feynman in 1959 (Majeed & Taha, 2013; Alireza et al., 2013; Majeed et al., 2014; Pashabavandpouri & Jahangiri, 2015), and after this time many scientists started introducing this technology to their fields. Basically, nanometric scale is the range of the particle sizes that this technology deals with Pusadkar et al. (2017). Nanomaterials are the materials where one of their dimensions is within the range of 1-100 nm, for these materials all the properties are still the same, compering to the bulk materials, but the nano scale provides these materials with very high cation exchange capacity and very high ratio of surface area to volume, these two properties make them to be very active to react with other materials and solutions (Majeed et al., 2014; Taha & Alsharef, 2018). Furthermore, and during the last two decades, nanomaterials were used in many industries and products such as, medicine, manufacturing, computer science and technology, and electronics etc. (Taha & Alsharef, 2018). In civil engineering applications, the nanomaterials have already been used, but in geotechnical applications, the use of these materials is still very limited, therefore very few studies, which describe the use of nanomaterials to modify or stabilize soils, are available.

From the available studies, it can be found that plastic soils were treated with some types of nanomaterials, for instance Taha & Taha (2012) conducted a study by using three different types of nanomaterials (nano-clay, nano-alumina, and nano-copper) to treat four types of plastic soils (two CL and two CH), the results indicated that the nanomaterials reduced swelling and shrinkage strains, and even reduced the desiccation cracks on the surface of the soil. Further the nanomaterials also has been used with other traditional additives in order to investigate their effects on soil modification, like the study which was done by Pashabavandpouri & Jahangiri in (Pashabavandpouri & Jahangiri, 2015) when they mixed nano-silica and lime with plastic soil (classified as CH) with different curing times, the findings indicated that this mix increase the strength, and compaction, and reduce swelling, and plastic properties of the soil, in addition to that, they found that the strength was increased rapidly (less time) when the nano-silica was introduced to the clay-lime mixture. Pusadkar et al. (2017) used nano-copper to treat black cotton soil, their finding showed that the optimum non-copper content was 1.5%, however with this amount the following engineering properties were increased; plasticity of the soil, maximum dry density, unconfined compressive strength, and the CBR value, whereas the optimum moisture content and the swelling pressure reduced. Naval et al. (2017) also found that the use of nanomaterials (Nano MgO and Nano Al2O3) contributed to the reduction of the swelling pressure for an expansive type of soil which was classified as a (CH).

This study contributes to the knowledge on how the addition of nanomaterial, which is magnesium oxide (MgO), will affect the engineering properties of specific type of plastic soil classified as (CH) from Mosul city-Iraq. Four percentages of MgO were mixed with the soil (0.25, 0.5, 0.75, and 1%), with different curing times (3,7,14,28, and 56 days).

2. Materials and methods

2.1 Materials

In Mosul city- Iraq, as stated earlier, clayey soils exist in vast area of the city. Hay Al-Seddek is one of regions located in Mosul city and it is known with its clayey soil. Soil samples, in disturbed condition, were sealed with plastic and brought to the geotechnical lab to run soil index tests (i.e. Atterberg limits, specific gravity), physical tests (i.e. grain size distribution), mechanical tests (compaction, consolidation, swelling) according to ASTM standards. The results of the grain size distribution are illustrated in Figure 1. Index soil properties and soil compaction characteristics were presented in Table 1.

The additive used in this study which is shown in Figure 2 is Magnesium Oxide (MgO), an industrial nano material. The MgO is a white solid powder with a purity of 99.9% and particle sizes ranging between 20-30 nm. The procedure of mixing the soil with the MgO was that specified percentages of MgO mixed with an oven dry soil. The percentages of MgO were 0, 0.25, 0.50, 0.75, and 1.0% by weight of dry soil sample. The mixing process was that the MgO has been added in liquid phase to the soil sample and mixed thoroughly. For the purpose of aging, homogeneity, and possible reactions, the mixture was usually placed in a sealed bag for 24 hours. Under X-ray spectroscopy, Salem et al. (2020) noticed a concentration change in the main component of mixture when MgO mixed with soil in the presence of water. The observed change is that the Oxygen and Magnesium concentrations increase while the Aluminum and Silicon concentrations decrease. This is clear evidence that chemical

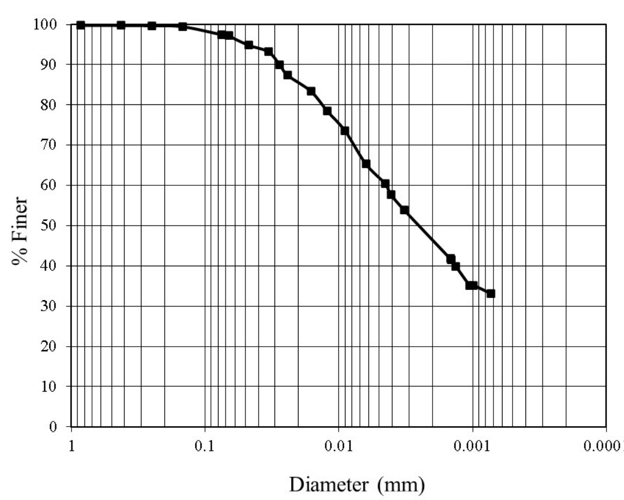

Figure 1. Grain size distribution of natural soil.

reactions have been occurred between the additive and soil components. Moreover, portions of Aluminum and Silicon were dissolved in the Hydroxide solution, and this causes such concentration changes. These results have been confirmed by the findings of Park et al. (2020), Wu et al. (2018), Yi et al. (2015). These reactions of silica presented in untreated soil with the Magnesium Hydroxide form the Magnesium Silicate Hydrate (CSH) which is responsible for the bonding forced between soil particles. This reaction is similar to the reaction of Portland cement with clay soils, which forms the CSH compound (Wu et al., 2018).

2.2 Specimens preparation of oedometer tests

The specimen preparation process stats by crushing a dry soil and sieving it on sieve #40. Specimens were prepared at soil compaction characteristics presented in Table 1 where the test has been conducted according to ASTM D698-12 (ASTM, 2021). For treated soil samples, each specified percentage of MgO had been dissolved in the 25% of water first, the solution was added to the dry soil and mixed thoroughly. The mixture was put in sealed plastic bags for 24 hours. The samples were statically compacted at a strain rate of 1 mm/min in the consolidation ring to their maximum dry densities. The prepared treated soil specimens were cured at 25 ºC for different curing times including 3, 7, 14, 28, 56 days.

A total of 21 soil specimens had been prepared for consolidation and swelling tests. After the completion of the consolidation / swelling tests, the specimens were taken out of the cell, oven dried at 60 ºC for 48 hours. Then, the dried specimens were grounded, sieved on # 40, and tested according to the ASTM specifications for Atterberg limits, potential hydrogen (*pH*-value), and electrical conductivity (*EC*).

2.3 One-dimensional oedometer test

Oedometer tests were conducted using Oedometer device to measure the free swell, swell pressure, and the consolidation characteristics of both treated and untreated soil specimens. First, on top and bottom of the soil specimens, filter papers have been positioned for the purpose of preventing soil particles from entering the pores of the stones The porous stones, which were kept in distilled water to reach saturation, were positioned on both sides of the soil specimen. The compacted specimen was put in the cell, then it was placed in the Oedometer device. Initially, vertical pressure of 6.9 kPa was applied. Water was poured until the cell was filled. Sensitive dial gauge (LVDT) for vertical movement measurements is fixed on the top of the cell. During testing, an increase in the height of specimen was measured for the purpose of calculating the free swell of the tested soil specimens. After that, loads were added to return the tested specimen to its original height for the purpose of measuring the swelling pressure of the tested soil specimens. The consolidation test has been performed according to ASTM D-2435 (ASTM, 2020) standard.

3. Results and discussions

3.1 Atterberg limits

Table 2 and Figures 3, 4 and 5 show the results of Atterberg limits of treated and untreated soil samples. Figure 3

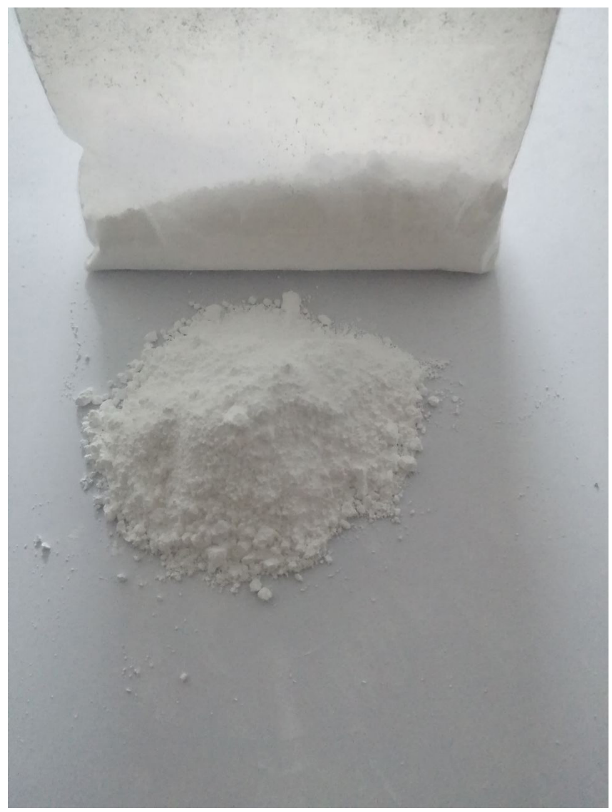

Figure 2. Nano MgO used.

Table 1. Soil properties of natural soil used in the study.

Soil properties		Standard Specifications	Value
Specific gravity G_s		ASTM D854-14. (ASTM, 2014)	2.75
Atterberg Limits	Liquid limit, *LL* (%)	ASTM D4318-17e1. (ASTM, 2018)	58
	Plastic limit, *PL* (%)	ASTM D4318-17e1. (ASTM, 2018)	32
	Plasticity index, *PI* (%)		26
Unified soil classification system (USCS)			CH
Compaction characteristics	Maximum dry unit weight (g/cm^3)	ASTM D698-12. (ASTM, 2021)	1.55
	Optimum moisture content (%)		25.0

shows that the liquid limit (*LL*) increases clearly with the nano percentage up to 0.75% then it decreases for higher nano content. Quantitatively, at 0.75% nano content, the *LL* is 71% which is approximately 1.22 times the *LL* of untreated soil. The plasticity index (*PI*) of the clayey soil- nano MgO mixture increases with the nano percentage up to 0.75% too. The maximum reported *PI* value is 35% at 0.75% nano content which is approximately 1.35 times the *PI* of untreated soil. For higher nano material content, the *PI* decreases, but the values of both *LL* and *PI* at 1.0% nano MgO content, which is the highest nano material percentage used in this study, are still higher than that of untreated soil. In addition, it is observed that the *LL* and *PI*'s results follow the same pattern.

In literature, the Atterberg limit's response to MgO content has been explained using different hypotheses. For example, Due to their tiny size, Nanomaterials have high specific surfaces which increase the wet surface area and the amount of adsorbed water. Resulted in an increase in the liquid limit and plasticity index (Tarsh et al., 2021). Moreover, the *PL*'s response to MgO content was explained adopting diffuse double layer (DDL) concept. It is common knowledge that water molecular is dipolar which is attracted to the cations and charged clayey particle surface with negative charge. Therefore, hydrogen bond is formed. Such behaviour governs the plastic limit of clayey soils. However, for higher nano material content, the reduction in Atterberg limits may be due to the agglomeration of nanomaterials when the percentage of nano (silica fume, fly ash) exceeded 3% (Tarsh et al., 2021). Masrour et al. (2021) mentioned that the addition on nano material to the clay soil leads to increasing both the

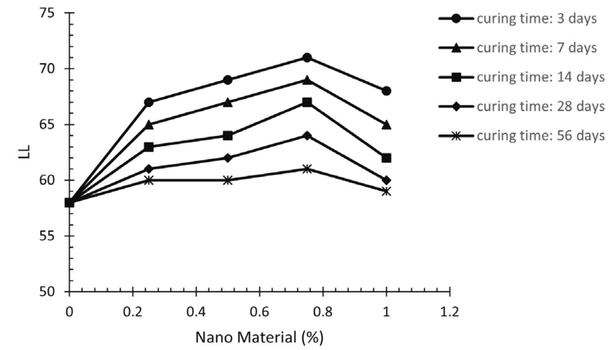

Figure 3. Effect of nano-MgO material and curing time on liquid limit (*LL*) value.

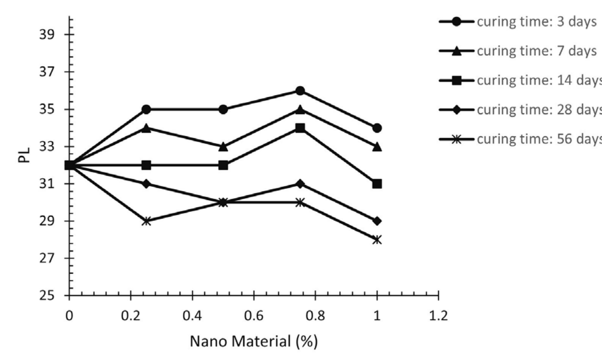

Figure 4. Effect of nano -MgO material and curing time on plastic limit (*PL*) value.

Table 2. Index and chemical properties of nano-MgO treated soils.

Curing time (day)	Nano (%)	Soil Properties					
		G_s	*LL* (%)	*PL* (%)	*PI* (%)	*pH*	*EC* (mS/m)
NA	Natural soil	2.75	58	32	26	7.7	285.5
3	0.25	2.74	67	35	32	7.8	208.0
	0.50	2.71	69	35	34	8.2	180.2
	0.75	2.71	71	36	35	8.7	184.5
	1.00	2.72	68	34	34	8.5	179.9
7	0.25	2.76	65	34	31	8.0	181.4
	0.50	2.75	67	33	34	8.3	176.5
	0.75	2.72	69	35	34	8.4	188.6
	1.00	2.70	65	33	32	8.6	254.5
14	0.25	2.68	63	32	31	7.9	232.0
	0.50	2.68	64	32	32	8.1	206.0
	0.75	2.67	67	34	33	8.5	170.8
	1.00	2.68	62	31	31	8.5	184.6
28	0.25	2.64	61	31	30	7.8	222.0
	0.50	2.56	62	30	32	8.2	206.0
	0.75	2.68	64	31	33	8.3	195.5
	1.00	2.68	60	29	31	8.5	216.6
56	0.25	2.63	60	29	31	7.8	228.0
	0.50	2.65	60	30	30	8.0	213.0
	0.75	2.69	61	30	31	8.4	171.2
	1.00	2.67	59	28	31	8.6	187.3

liquid and the plastic limits. This behaviour is attributed to the formation of calcium–silicate–hydrate (CSH) gel and reduction of the porous structure were noticed through the XRD results and SEM micrograph after 28 days of curing. Pashabavandpouri & Jahangiri (2015) confirmed that adding nano material to clay causes Atterberg limits to increase since the nanomaterials have high specific surface. Hence, the amount of water surrounded by mixture particles increases which results in increasing plasticity parameters of soil mixed with nano materials.

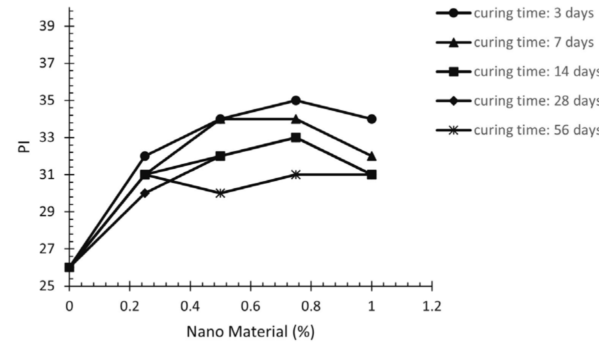

Figure 5. Effect of nano-MgO material and curing time on plasticity index (*PI*) value.

3.2 Consolidation characteristics

The compression index is one of the critical parameters used to characterize soil compressibility. The relationship between measured compression index and nano-MgO mixing content is plotted in Figure 6. Results presented in Table 3 and Figure 6 show that the compression index of specimens without nano-MgO is the greatest, which is 0.256. For treated soil specimens with nano-MgO, the compression index decreases. When the nano-MgO mixing content is about 0.75%, the compression of the soil sample reaches a minimum value. When the nano-MgO mixing content is higher, the compressibility is insignificantly changed. Quantitatively, results show that the compression index decreases by 4.6, 15.2, 20.3and 21.1% for nano-MgO mixtures of 0.25,0.50. 0.75, and 1.0%, respectively. This finding shows that the compressibility of the clayey soil is significantly reduced by adding a small amount of nano-MgO.

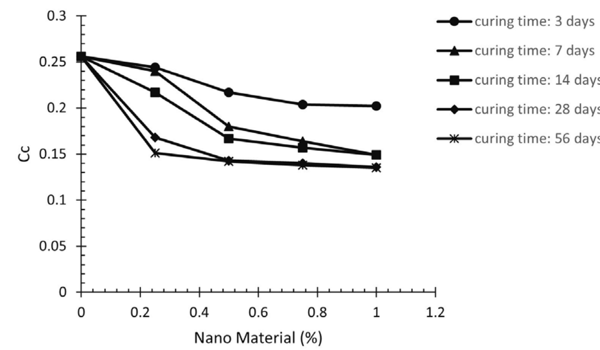

Figure 6. Effect of nano-MgO material and curing time on compression index (C_c) value.

Table 3. Consolidation and swelling characteristics of natural and nano-MgO treated soil specimens.

Curing Time (day)	Nano (%)	Consolidation Characteristics			
		C_c	C_s	Free swell (FS) (%)	Swell Pressure (*SP*) (kPa)
NA	Natural soil	0.256	0.0522	6.0	200
	0.25	0.244	0.0484	4.5	180
3	0.50	0.217	0.0467	4.8	160
	0.75	0.224	0.0495	5.6	162
	1.00	0.202	0.0405	5.1	158
	0.25	0.240	0.0469	3.8	150
7	0.50	0.180	0.0408	4.0	145
	0.75	0.164	0.0209	4.7	155
	1.00	0.149	0.0346	4.5	160
	0.25	0.217	0.0539	4.0	160
14	0.50	0.167	0.0481	5.0	152
	0.75	0.157	0.0482	5.2	150
	1.00	0.149	0.0418	4.2	145
	0.25	0.168	0.0395	4.2	150
28	0.50	0.143	0.0434	4.2	135
	0.75	0.140	0.0447	4.5	120
	1.00	0.136	0.0229	3.8	110
	0.25	0.151	0.0284	4.1	160
56	0.50	0.142	0.0476	5.3	100
	0.75	0.138	0.0499	5.8	140
	1.00	0.135	0.0504	4.7	131

Not only, adding small amount of nano-MgO contributes enhancing the clayey soil settlement, but also the curing time. Results reveal that the curing time causes to decrease the compression index of nano-MgO, especially for the curing time between 3 to 28 days, while for higher curing time (i.e. 56 days), the curve shows slightly lower than that of 28 days. Quantitively, it is noticed that for the longest curing time utilized in this study, the compression index decreases by 41.0, 44.5, 46.1, 47.3% for the 0.25%, 0.5, 0.75, and 1.0% nano-MgO content, respectively. This indicates that the compressibility of the clayey soil is also decreased because of curing time. In conclusion, results imply that the nano-MgO of 0.75 is the optimum content for reducing the settlement of clayey soil used in this study. Similar findings have been reported by Cheng et al. (2020), where the consolidation characteristics has been improved using nanomaterials.

3.3 Swelling characteristics

Constant volume method was adopted for swelling pressure testing while free swelling method for swelling. Swelling characteristics of clayey soil were measured for varying amount of nan-MgO 0, 0.25, 0.5, 0.75, and 1.0% and for different curing time of 3, 7, 14, 28, and 56 days. Results showed that when nano-MgO particles was added, a significant change in the magnitude of swelling was observed for all the nano-MgO percentage in comparison to the untreated soil specimens, as shown in Table 3 and Figure 7. The figure illustrates the relationship between measured free swell and nano-MgO mixing content. Results show that the free swell of specimens without nano-MgO is the maximum, which 6%. For treated soil specimens with nano-MgO, the free swell decreases and the minimum value of the free swell is reported for the nano-MgO of 0.25%. For higher nano-MgO content, the free swell slightly increases in comparison to the value of the 0.25%. but it is still less than the free swell of untreated soils specimens. Quantitatively, results show that the free swell decreases by 25, 20, 7 and 15% for nano-MgO mixtures of 0.25,0.50. 0.75, and 1.0%, respectively. This finding reveals that the free swell of the clayey soil is largely reduced by adding a small amount of nano-MgO which is 0.25%. Curing time is also a vital factor affecting the change in the free swell of nano-MgO treated soil specimens. Results show that the curing time causes to decrease the free swell of nano-MgO treated soil specimens and the maximum reduction is achieved at nano-MgO of 0.25%. For higher nano-MgO content, the reduction in free swell is lower in comparison to the untreated soil specimens. Quantitively, it is noticed that for the longest curing time utilized in this study, the free swell decreases by 31.7, 11.7, 3.3, 21.7% for the 0.25%, 0.5, 0.75, and 1.0% nano-MgO content, respectively. This indicates that the swelling of the clayey soil is also reduced because of curing time. In conclusion, results imply that the nano-MgO of 0.25 is the optimum content for improvement the free swell behaviour of clayey soil used in this study. Using nano-MgO as an additive, Naval et al. (2017) confirmed that the swelling potential has significantly decreased.

The swell pressure is crucial parameter in characterizing soil swelling behaviour. Table 3 shows that swell pressure of untreated soil specimens is 200 kPa and it varies from 130 to 180 for nano-MgO treated soil specimens. The swell pressures presented in Figure 8 quantify the magnitude of swelling observed. All swelling pressures in the presence of nano-MgO display approximately similar trends. Generally, the swell pressure decreases with the nan-MgO content up to 0.75%. For higher nano-MgO content, an insignificant reduction of the swell pressure has been recorded. Quantitively, the reduction of swell pressure at the nano-MgO of 0.75% is 19%. Curing time also contributes in the reduction of the swell pressure of nano-MgO treated soil specimens. Results show that the curing time causes to decrease the swell pressure of nano-MgO and the maximum reduction is achieved approximately at nano-MgO of 0.75%. For higher nano-MgO content, the reduction change in swell pressure is only slightly. Quantitively, it is noticed that for the 28 day- curing time, the swell pressure decreases by 25, 32.5, 40, 45% for the 0.25%, 0.5, 0.75, and 1.0 nano-MgO

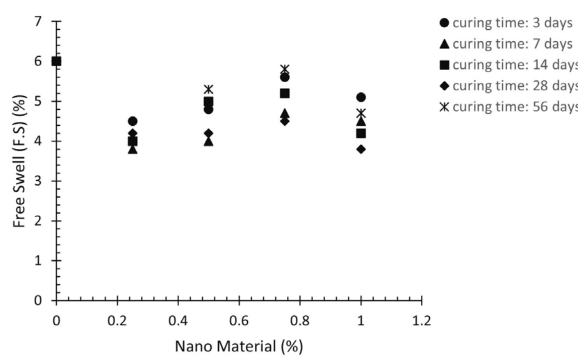

Figure 7. Effect of nano-MgO material and curing time on free swell (*FS*).

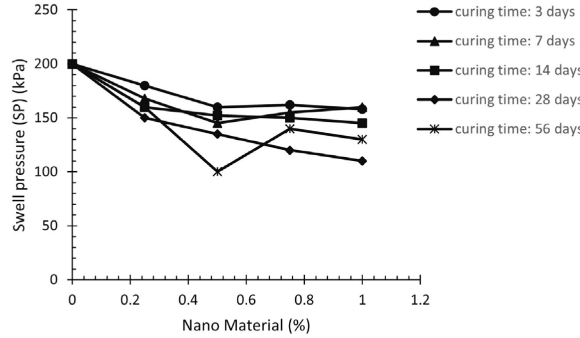

Figure 8. Effect of nano-MgO material and curing time on swell pressure (*SP*).

content, respectively. This indicates that the swell pressure of the clayey soil is significantly reduced because of curing time.

3.4 *pH*-value

The results of the *pH* values of both treated and untreated soil specimens have been presented in Table 3 and Figure 9. They show that the *pH* values increase as the nano percentage increases up to 0.75% then the rate of increasing significantly decreases for higher nano content. Quantitatively, at 0.75% nano content, the reported *pH* is 8.7 which is approximately 1.13 times the *pH* of untreated soil. Similar findings have been reported by Alsharef et al. (2016). Not only the effect of the nano material content on *pH* values has been investigated, but also the effect of curing time. Curing time is considered an important governed parameter for the time-dependent action between the soil and the additive. Results show that the *pH* decreases with the curing time for all the different nana MgO that is added. Quantitively, for instance, the *pH* value of specimen treated with 1% MgO, increases by 15% in comparison to the natural soil at 3 days curing time. However, for the same percent of additive, the *pH* increases only by 8%. This indicates that the curing time causes decrease in the *pH* value to approximately half. The reduction in the *pH* with curing time can be attributed to forming of agglomeration material. This increase in *pH* value is an indication of increasing soil alkalinity of the treated soil. Alkalinity might cause to dissolve some components of soil, which implying chemical reactions (Ikeagwuani et al., 2019). Moreover, the increase in the *pH* value causes soil particles to agglomerate, consequently soil properties enhance (Ruan et al., 2020; Salem et al., 2020).

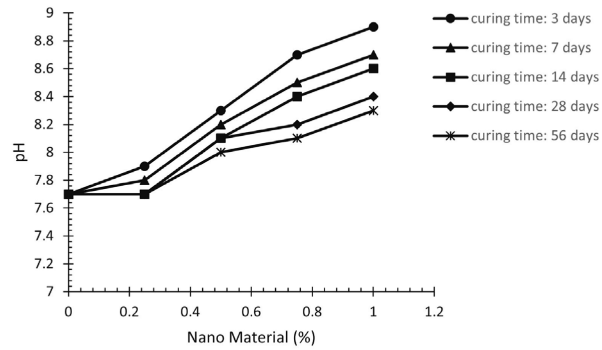

Figure 9. Effect of nano-MgO material and curing time on Potential of Hydrogen (*pH*).

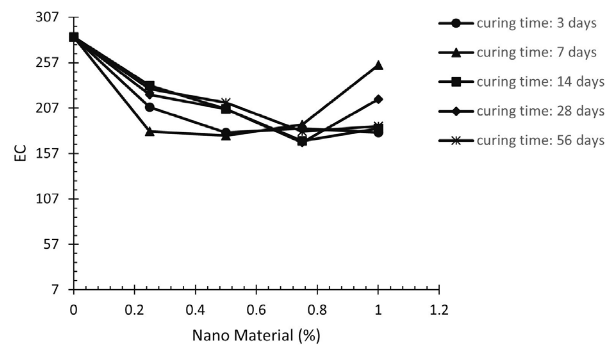

Figure 10. Effect of nano-MgO material and curing time on Electrical Conductivity (*EC*).

3.5 Electrical conductivity (*EC*)

In the absence of nano-MgO, the magnitude of *EC* is 285.5. This magnitude changes when the nano-MgO is added to the soil. The results of the *EC* values of both treated and untreated soil specimens have been presented in Table 3 and Figure 10. They show that the *EC* value decreases with the nano-MgO content up to 0.75% nano-MgO content, then it slightly increases for higher nano-MgO content. Therefore, the maximum reduction percent is reported at 0.75 nano-MgO which is approximately 35%. Not only the effect of the nano material content on *EC* values has been investigated, but also the effect of curing time. Results show that the *EC* decreases with the curing time for all the different MgO that is added. Quantitively, the specimen treated with 0.75% nano-MgO, and 28 days curing time decreases by 41% in comparison to the natural soil. In compassion to the 3 days curing time, it is noted that the *EC* decreases by 8%. This indicates that the curing time causes to decrease the change in the *EC* value significantly. Aizat et al. (2014) reported that soil electrical conductivity is negatively related with soil *pH* in the form of power function. Lower soil *pH* indicates a larger number of hydrogen ions in the soil. Soil electrical conductivity level is affected by hydrogen ions. The higher the amount of hydrogen ions in the soil, the higher the rate of electrical conductivity. Hence, high soil *pH* due to low number of hydrogen ions in the soil may decrease soil electrical conductivity.

4. Conclusion

A series of lab experimental tests has been conducted on 21 soil specimens to investigate the effect of nano material represented by magnesium oxide (MgO) on the geotechnical clayey soil characteristics from Mosul city. The conclusions that have been driven for the study are that the free swell and swell pressure of the soil specimens have been reduced by 25%, and 19%, respectively for 0.25, and 0.75% content of nano material under 3 days of curing time and at curing temperature of 25 ºC. It also concludes that the compressibility characteristic represented by the compression index parameter has been reduced by 20.3% for 0.75% of nano-MgO material while, the soil plasticity index exhibits a maximum increasing at 0.75% of nano content and the *pH* value increases while the *EC* decreases with the nano-MgO content. Moreover, the free swell and swell pressure for untreated and treated soil specimens was taken during different periods of curing time.

It is concluded that the highest reduction occurred after the 28 days curing time, and it is respectively 31.7% and 45% respectively, for the free swell and swell pressure after 28 days of curing. Furthermore, the compression index of treated soil decreases by approximately half for curing time of 28 days. In sum, the swelling and consolidation reduction with curing bring the significant improvement and promising results for the treated samples. Thus, the results have confirmed the strong potential use of the nano MgO in reducing the negative effects of swelling and compressibility on the soil characteristics.

Declaration of interest

The authors have no conflicts of interest to declare. All co-authors have observed and affirmed the contents of the paper and there is no financial interest to report.

Authors' contributions

Zeena Al-Khazzaz: investigation, methodology, experimental testing. Abdulrahman Aldaood: investigation, methodology, experimental testing, results analysis. Muwafaq Awad: writing - original draft preparation, reviewing, editing. Mohammed Kamil Faris: writing - original draft preparation, reviewing.

Data availability

Enquiries about data availability should be directed to the authors.

List of symbols

pH	potential of hydrogen
C_c	compression index
CH	high plasticity clay
CL	low plasticity clay
C_s	swell index
DDL	diffused double layer
EC	electrical conductivity
FS	free swell
G_s	specific gravity
LL	liquid limit
NA	natural
PL	plastic limit
PI	plasticity index
MgO	magnesium oxide
USCS	unified soil classification system
SP	swell pressure

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