Treatment of Soft Soil with Nano Magnesium Oxide

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Abstract The effect of nano magnesium oxide on some geotechnical properties of a local soil is investigated. Four different remolded water contents were used to prepare the tested specimens. These water contents represent the optimum and wet of optimum conditions. The soil was then mixed with nano magnesium oxide ranging between 0 to 1.0 % by dry weight of soil. Consistency limits and unconfined compression tests were conducted to study the change in basic soil behavior. The results of the study indicated that the plasticity index exhibits significant reduction compared with untreated soil. The reduction is in proportion with curing time and nano magnesium oxide surface area (i.e. by using N-MgO) as well as the doses of N-MgO. The unconfined compressive strength of treated soil increased significantly over time with increasing percentage of N-MgO. The mechanical behavior of treated soil changed from ductile to brittle associated with remarkable increase in Young's modulus. The results also revealed that the stiffness developed from soft and medium stiff in the case of original soil to a very stiff soil particularly for soil – N-MgO mixtures.

1 Introduction

In many cases in practice, the construction of engineering structures has to deal with high water content soils to support its foundation. These soft soils are characterized by low bearing capacity and high compressibility. Thus, treatment of high water content soil is important prior to construction. Chemical additives represent a solution which could be use to overcome the soft soil problem. The most conventional and popular additives used for soil stabilization are calcium – based additives [1, 2]. Soil treatment by calcium – based additives have been proven to provide a significant development in soil strength, workability, durability, and reduction in soil compressibility [1, 3-6].

Looking for alternative material to calcium – based additive is a matter of sustainability. Calcium oxide is produced from calcination of calcium carbonate where this process is carried out at high temperature makin it energy intensive and uneconomical production [7-10]. High solubility and reactivity of portlandite eases its carbonation or interaction with sulfate leading to swelling and reduction in the strength of soil-calcium mixtures [11-15].

A few studies have also been done to investigate the effect of magnesium-based additive on the properties of soil and clay minerals. Caillere and Henin; Gupta and Malik; Carstea et al.; Xeidakis; and Ureña et al. [16-20] showed that the addition of brucite to montmorillonite induced reduction in swelling potential. This study attempts to investigate the efficiency of regular and nano – magnesium oxide to improve the geotechnical properties of a residual soil.

2 Materials

2.1 Soil

The residual soil was obtained from within the campus of the Universiti Kebangsaan Malaysia (UKM), Bangi, Selangor, Malaysia. Residual soils cover about 75% of peninsular Malaysia and are thus a popular construction material. In this study, the soil was dug at a depth of 50 cm below natural ground level. Table 1 illustrates the physical and chemical characteristics (obtained from X-ray fluorescence (XRF) test) of the obtained soil. The tested soil is an acidic soil i.e. pH value of 4.65.

Table 1 Basic properties of the tested soil

Physical properties		Chemical composition	
Property	Value	Formula	Concentration
Natural moisture content, (ω_n) (%)	22.0	SiO	60.35 %
Maximum dry density, γ_{dmax} (g/cm^3)	1.78	Al_2O_3	21.83 %
Optimum moisture content, (ω_{opt}) (%)	16.0	Fe_2O_3	4.36 %
Liquid limit, (LL) (%)	31	TiO_2	1.13 %
Plastic limit, (PL) (%)	19	K_2O	0.51 %
Plasticity index, PI (%)	12	MgO	0.47 %
USCS classification	CL	ZrO_2	0.09 %
pH- value	4.65	SO_3	0.08 %
% Gravel	0.0	P_2O_5	0.05 %
% Sand	59.5	CaO	0.05 %
% Silt	20.5	Others	0.03 %
% Clay	20.0		

2.2 Magnesium oxide

Two grades of magnesium oxide powders were used in this study, i.e. regular magnesium oxide (R-MgO) and nano magnesium oxide (N-MgO) of high purity which were supplied by Inframat Advanced Materials Company, Manchester, USA. The specific surface area of R-MgO was 20 m^2/g, while for N-MgO was 50 m^2/g with density of 3.60 g/cm^3 for both of materials. Based on XRF analysis, the purity of R-MgO was 99.46% which is higher than that of N-MgO (95.66%). Some physical and chemical properties of these materials are shown in Table 2.

Table 2 Chemical and physical characteristics of the R-MgO and N-MgO powders

Chemical composition (XRF test)			Physical properties (Inframat Advanced Materials)		
Formula	Concentration		Property	Value	
	R-MgO	N-MgO		R-MgO	N-MgO
MgO	99.46%	95.66%	Average particles size	0.5-2 µm	100 nm
CaO	0.20%	0.52%	Specific surface area	>20 m^2/g	>50 m^2/g
SO_3	0.17%	3.64%	Density (g/cm^3)	3.60	3.60
SiO_2	0.11%	0.08%	Melting point	2850^o C	2850^o C
Cl	0.03%	---	Boiling point	3600^o C	3600^o C
Fe_2O_3	0.02%	49 ppm			
Other	0.01%	0.095%			

3 Methodology

The tested soil was mixed with four dosages of magnesium oxide i.e. 0.0, 0.3, 0.5, 0.8 and 1.0 % by weight of dry soil. The change in soil consistency limits i.e. LL, PL and PI were investigated after two curing periods of 1 day and 28 days. The adopted method to determine the LL was cone penetrometer method, while rolling method was adopted for plastic limit following BS 1377-2:1990 standard. Four groups of mixtures were prepared. Each group involved mixing the soil with same dosages of magnesium oxide mentioned above and four remolded water contents (ω_r) of 16, 18, 20 and 22 %. These water contents represent optimum and wet of optimum water content (ω_{opt}). The mixing procedure involved mixing the fully dry soil with the required amount of water. The MgO was then added step by step and well mixed with soil sample to ensure that the MgO is well distributed over the soil sample particularly N-MgO. These mixtures were prepared for unconfined compression strength. Plastic wrap was used to keep the cylindrical specimens of the unconfined compression test for curing periods of 1, 3, 7, and 28 days. After obtaining the compressive strength for the mentioned curing periods, the modulus of elasticity was also calculated.

4 Results and Discussion

4.1 Impact on consistency limits

The results obtained from the consistency tests for soil – R-MgO mixtures are presented in Figure 2 a & b. Figure 2 c & d illustrate the results for soil – N-MgO mixtures. Generally, for curing period of 1 day the results showed that the LL of treated soil slightly decreased with increasing percentage of R-MgO (Fig. 1a). For curing period of 28 days, the LL experienced a more considerable reduction. Compared with the pure soil (LL= 31%), the LL for soil – 0.3% R-MgO mixture decreased to the minimum levels of 29.8% and 28.6% for 1 day and 28 days, respectively. This trend increased in the case of N-MgO. Similar to R-MgO, the mixture of 0.3% of N-MgO possesses the minimum values of LL of 27.3% and 26% for 1 and 28 days curing, respectively. Thereafter, increasing the amounts of R-MgO leads to almost no change in the LL values. For nano grade magnesium, however, the LL curve displayed rising trend for mixtures of N-MgO doses greater than 0.3%. However for all cases, the LL was still less than that for pure soil.

In contrast to LL, the general trend of PL variation is directly proportional to the dosage of MgO and curing period. It increased gradually with increasing R-MgO contents reaching 22.5% after curing of 1 day and 22.8% for 28 days curing. The same trend can be seen for soil – N-MgO mixtures. The maximum values the PL reached were for 1.0% N-MgO which was 21.8% and 24.7% for 1 and 28 days curing period, respectively. Exceptional behavior for mixture of 0.3% N-MgO can be observed from Figs 1 b & d. For PI, the tendency is reversed with respect to the percentage of MgO and curing period. A noticeable reduction in PI can be detected after first day of curing. However, the reduction becomes more significant after 28 days of curing period. In addition, the N-MgO has greater effect to reduce the PI of the treated soil. This behavior of PI reduction compared to the virgin soil is largely similar to that of soil treatment by lime where this reduction reflects increasing soil workability, decreasing the sensitivity of soil strength to the moisture and reduce the shrinkage and swell potential [1, 21-23].

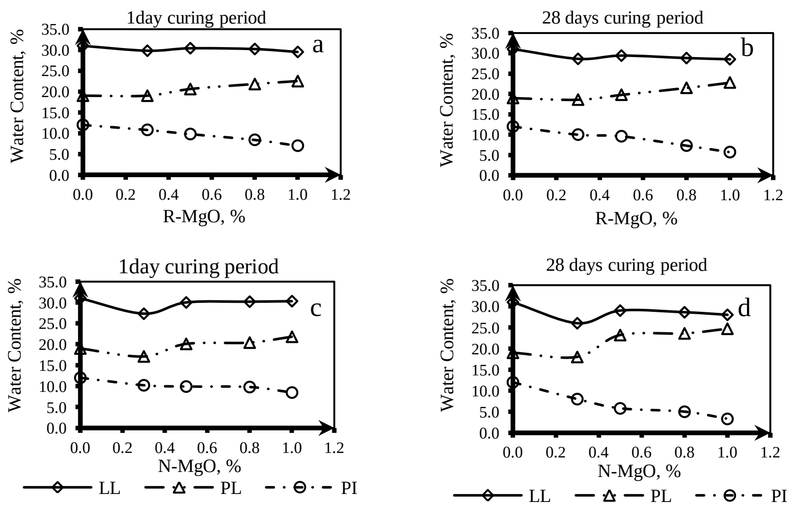

Fig. 1. Change in consistency limits for 1 and 28 days curing periods.

4.3 Impact on unconfined compressive strength and deformation

Figs 2 and 3 show the strength gain over curing period for various contents of R and N-MgO. The results of unconfined compression test for the pure soil show that there was a high sensitivity towards the remolded water contents (ω_r). Although the unconfined compressive strength (UCS) for ω_r at ω_{opt} (16%) was 151.19 kN/m^2, the strength drops to 84.63, 53.245 and 29.13 kN/m^2 at ω_r at 18, 20, and 22 %, respectively. However, a dramatic increase in soil strength with curing time was realized after mixing the tested soil with MgO and this strength gain was directly proportional to the curing periods. Fig 2 demonstrates that increasing the amount of MgO increases the unconfined compressive strength (UCS). In the same context, N-MgO induced noticeable increase in UCS of soil – MgO mixtures, i.e. the strength of the mixtures with N-MgO was higher than the strength of mixtures with R-MgO (Fig 3). These may be due to higher ability of N-MgO to flocculate and agglomerate the soil particles compared with the regular grade. In addition, the R-MgO could fill only the micro pores while N-MgO could fill the micro and nano pores as well.

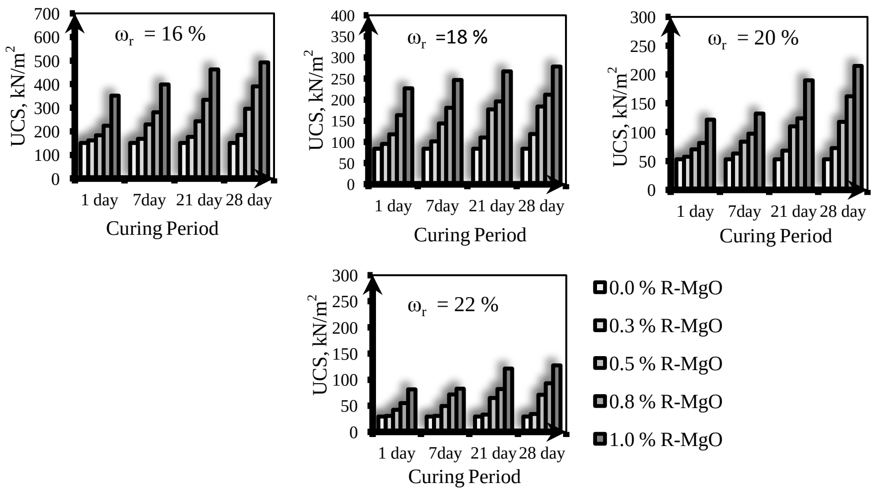

Fig. 2. UCS developments for different for soil – R-MgO mixtures

From this point of view, the mixtures of N-MgO experienced less axial deformation which coincides with decreasing axial failure strain compared with R-MgO. This behavior can be represented by Young's modulus in which our results showed increase in Young's modulus over curing period for different % of MgO and remolded water content. It was also found that the increase in Young's modulus for the treated soil is in proportion with the MgO contents and curing periods as well as the surface area of the MgO i.e N-MgO. Meanwhile, the ω_r inversely affects the Young's modulus. The increase in modulus of elasticity of treated soil points to the change in the mechanical behavior from ductile to brittle [4, 24].

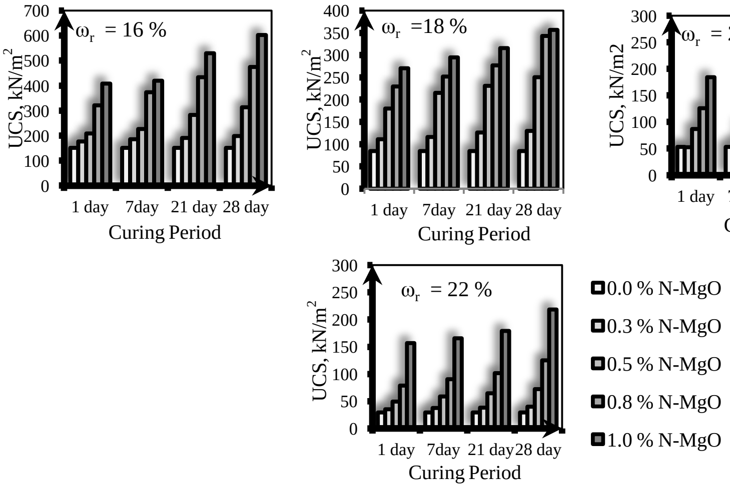

Fig. 3. UCS developments for soil – N-MgO mixtures

Fig 4 presents the stiffness development of treated soil after 28 days curing period (classification following Das [25]). At 1.0% MgO, it is evident that the soil stiffness developed from soft and medium stiff soil in the case of original soil to a stiff soil for the mixtures of ω_r of 20% and 22%, and to a very stiff soil for ω_r of 16% and 18%. All the mixtures treated with N-MgO, however, developed to a very stiff soil.

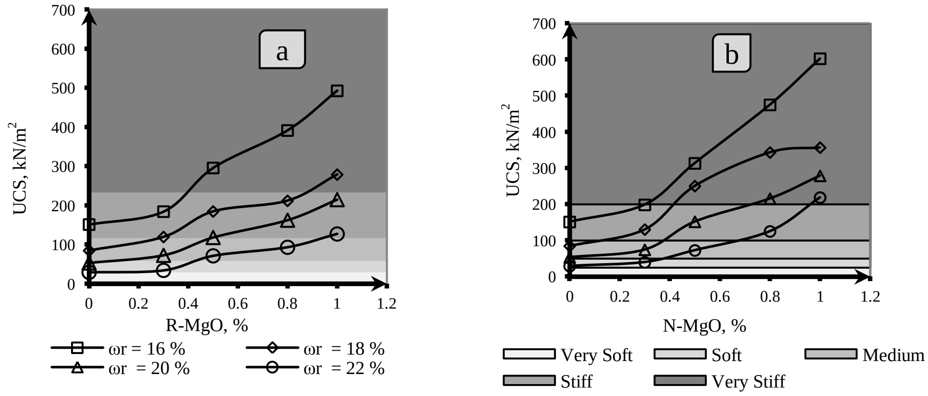

Fig. 4. Stiffness development over curing period of 28 days for different remolded water contents (a) Soil – R-MgO mixtures, (b) Soil – N-MgO Mixtures

5 Conclusion

Based on the obtained results, the following conclusions can be drawn:

a. The plasticity index exhibits significant reduction compared with untreated soil. This reduction is in proportion with curing time and magnesium oxide surface area (i.e. by using N-MgO) as well as the doses of magnesium oxide.
b. The unconfined compressive strength of treated soil increased significantly over time with increasing percentage of magnesium oxide. This strength gain is inversely proportional to the remolded moisture content.
c. The mechanical behavior of treated soil changed from ductile to brittle associated with remarkable increase in Young's modulus.
d. The results also revealed that the stiffness developed from soft and medium stiff soil in the case of original soil to a very stiff soil particularly for soil – N-MgO mixtures.
e. The use of N-MgO induced higher ability to improve geotechnical properties of a tropical residual soil.

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