INFLUENCE OF MAGNESIUM CARBONATE ON THE GEOTECHNICAL PROPERTIES OF CLAYEY SOILS

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1. INTRODUCTION

With the climate change crisis becoming more dire with every coming decade, limiting global temperature rise to 1.5°C now require the implementation of negative emission technologies capable of carbon capture and storage. Among the many developments in this regard is a desalination brine conversion process proposed by Myers and Nakagaki (2021), where the product MgO can be further used to mineralize CO_2 and produce $MgCO_3$. This enables about 4.5 kg-CO_2/m^3-brine of negative emissions, thereby establishing its mitigation potential.

On the other hand, research involving the use of industrial waste materials as ground improvement materials have been on the rise. Most research in this area focus on the use of industrial waste materials like fly ash and basalt fibers. In the realm of using carbonates as such geomaterials, most research focus on the physical properties observed as a result of calcium carbonate precipitates occurring from liming precipitation reactions and the upcoming microbially induced carbonate precipitation reactions or MICP (Almajed, et. al, 2019). However, very little to no data is available on the effects of $MgCO_3$ as such a geomaterial. Therefore, in this study, the practical applicability of $MgCO_3$ is investigated based on the unconfined compressive strength characteristics (q_u) and pH of soil mixtures with varying amounts of $MgCO_3$ in comparison to pure soil cases. Furthermore, empirical equations have been proposed to predict plastic (PL) and liquid limits (LL) based on the $MgCO_3$ percentage in the soil.

(a) TAC-1 (b) $MgCO_3$ Fine powder
Fig. 1. Materials used in this study

Table 1. Engineering Properties of TAC-1

Parameters	Values	Method standard
Specific Gravity, G_s	2.69	JIS A 1202:2009
Atterberg limits: Plastic Limit, PL (%) Liquid Limit, LL (%) Plasticity index,PI	 28.1 46.6 23.9	JIS A 1204:2009
Compaction: Maximum Dry Density, $r_{d,max}$ (g/cm^3) Optimum water content, w_{opt} (%)	 1.57 25.7	JIS A 1210:2009
Soil Classification	CL (low plastic limit clay)	JGS 0051-2009

2. TEST MATERIALS AND PROCEDURE

Two commercially available materials- TAC-1 (a clayey soil hereafter called 'soil'; Fig.1.a.) and $MgCO_3$ fine powder (Fig. 1.b.) were mainly used in the study. The former is plastic and has its engineering properties listed in Table 1. The $MgCO_3$ powder is non-plastic, relatively finer with a 2.3 specific gravity and is hygroscopic in nature, enabling it to be used in applications necessitating water adsorption, such as enhancing grip performance in gymnastics (Ropp, 2013). It is also a common component of fertilizers, known to increase the pH of acidic soils (Zhang, et. al, 2019). The natural pH of $MgCO_3$ in water was experimentally found to be 10.05.

Table 2. Compaction characteristics of soil-$MgCO_3$ mixtures

$MgCO_3$ percentage (wt.%)	0	10	20	30	40
Maximum Dry Density, $\rho_{d,max}$ (g/cm^3)	1.57	1.31	1.16	1.08	1.00
Optimum Water Content (wt.%)	25.7	26.0	30.4	44.3	60.5

The PL, LL and plasticity index (PI) of soil mixtures with 0-40 wt.% $MgCO_3$ were determined using the procedures outlined in JIS A 1205:2009 standard. The q_u characteristics were then determined for soil mixtures with 0,10, 20, 30 and 40 wt.% $MgCO_3$. Mixtures of each $MgCO_3$ percentage case was prepared with a water content respective to their experimentally found optimum water content from conducting compaction experiments using Standard Proctor method (as seen in Table. 2). The testing specimens were then prepared using a detachable cylindrical mold of 10 cm height and 5cm diameter. At least 4 specimens were made for each $MgCO_3$ percentage case by varying their compaction degrees (D_c) in the range of 75-90%. The soil in the specimen were compacted in 10 layers- each being 1cm in height and having 1/10th of the total soil mass. The topmost layer was trimmed to ensure uniform loading on a smooth surface. The prepared specimens were then wrapped in film and placed in airtight bags for 3-7 days. At the end of the period, they were placed in the uniaxial compression testing device and underwent loading until clear signs of failure were observed. Finally, the pH of soil mixtures with 0-40 wt.% $MgCO_3$ were tested using a combination of pH electrodes and a data logger. The samples were prepared such that each had 20g of dry soil mixture and 80g of distilled water) The pH values were noted from the data logger by inserting the pH electrode into the sample approximately 5 minutes after preparation.

3. RESULTS AND DISCUSSION

The PL and LL data were plotted graphically and shown in Fig. 2. A steady increase in both the limits were observed upon increase in the $MgCO_3$ percentage. PI values, which indicate the plasticity of the soil, are shown to remain near constant.

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This could be attested to the hygroscopic property of the $MgCO_3$ particles causing water adsorption and thereby requiring more water to be added for the soil to reach their PL and LL. Furthermore, equations to predict PL and LL values according to the $MgCO_3$ percentage (given as M_{MgCO_3}) in the soil were derived through simple linear regression analysis and are proposed as follows:

$$LL = 0.9589M_{MgCO_3} + 47.003 - - - (1)$$
$$PL = 0.7552M_{MgCO_3} + 26.017 - - - (2)$$

With R^2 values of 0.9783 and 0.9724, Eqn. 1. And Eqn. 2. can be used to estimate LL and PL values of $MgCO_3$ mixed soils quickly during ground investigations. Conversely, the $MgCO_3$ percentage within the ground can be estimated using their natural PL and LL values.

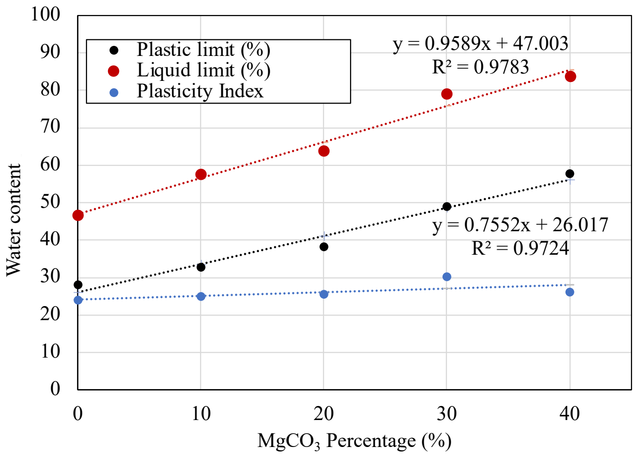

Fig.2. Plastic and liquid limits of soil mixed with 0-40 wt.% $MgCO_3$

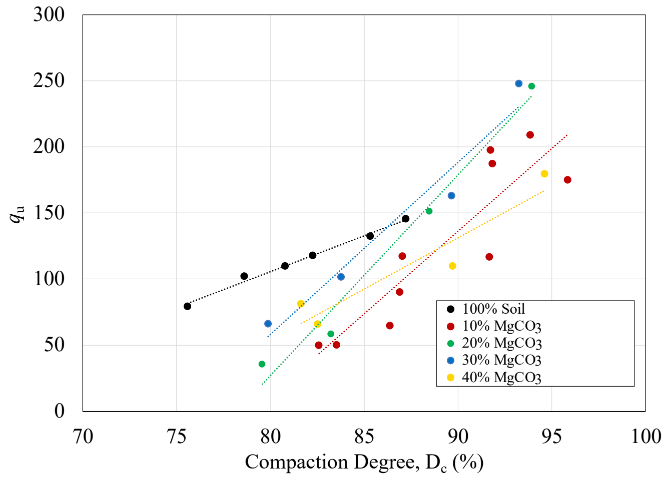

Fig. 3. q_u vs D_c graph soil mixed with 0-40 wt.% MgCO3

The obtained relationship between the q_u characteristics for each $MgCO_3$ percentage case and their corresponding D_c are shown in Fig 3. It was observed that the q_u of soil mixtures with 10-30 wt.% $MgCO_3$ were generally greater at higher D_c (i.e. D_c= 90-95%) in comparison to that of pure soil. It is possible that the increase in pores due to the addition of the finer-sized MgCO3 powder led to a greater capillary action and increased the suction or negative pressure between particles. This in turn could have increased the q_u values of these mixtures. However, a sudden drop in q_u values were observed at 40 wt.% $MgCO_3$, indicating a limit at which the greater suction could compensate for the loss of the primary cohesive forces as a result of non-cohesive $MgCO_3$ addition. In terms of practical applications, this would mean that the addition of maximum 30 wt.% $MgCO_3$ to the ground could be beneficial as a form of ground strength improvement of clayey soils in construction works. Studies are currently being undertaken to confirm and further evaluate the role of the suction effect within $MgCO_3$ mixed soils.

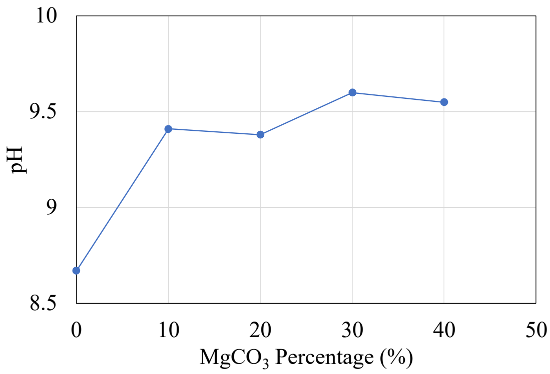

Fig.4. pH of soils mixed with 0-40 wt.% $MgCO_3$

Lastly, the obtained pH results for each $MgCO_3$ mixture case is shown in fig. 4. As expected, 10 wt.% $MgCO_3$ addition increased the pure soil's pH. However, further addition led to minimal increase in soil pH. This indicates that addition of $MgCO_3$ would be beneficial in reducing acidity in soils without the risk of over-basification.

4. CONCLUSION

Recognizing the need to improve upon the feasibility of a negative emission technology's $MgCO_3$ end material, this study evaluated PL, LL, PI, q_u and pH characteristics soil mixtures with 0-40 wt.% MgCO3. An increase in both PL and LL were observed upon increasing percentages of $MgCO_3$ within the soil. Furthermore, soils with 10-30 wt.% $MgCO_3$ showed greater q_u values than that observed in pure soil. The increased q_u is theorized to be as a result of a greater suction effect. Lastly, it was observed that while $MgCO_3$ increases soil pH, further MgCO3 addition does not significantly increase pH. Therefore, it is concluded that 10-30 wt.%$MgCO_3$ can be used as ground improvement material, especially in preventing soil acidification without running the risk of over-basification.

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