Study on unconfined compressive strength of magnesium carbonate and soil mixtures

Waseda University

Student Member Navya Ann Eldho
Member Hailong Wang
Nonmember Corey A. Myers
Student Member Kunlin Ruan
Nonmember Ding Rao

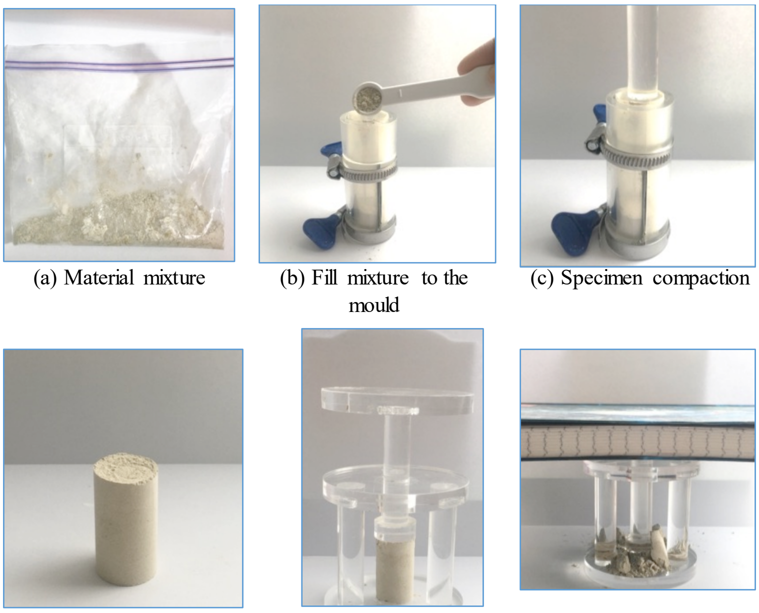
1. Introduction

Global warming is one of the most pressing issues human society faces today. According to the report by IPCC (2018), achieving the goal of limiting global warming to 1.5°C would require quick 'unprecedented changes in all aspects of society' to reduce carbon dioxide (CO_2) emissions due to human activities by 45% by 2030 and reach net zero emissions by 2050. Among many other upcoming technologies to achieve these lofty goals, Myers and Nakagaki (2021) proposed a negative emission technology during the conversion process of desalination brine using the method of electricity-driven evaporation and temperature control. In this process, brine is separated into a set of revenue-generating products, one of which is magnesium oxide (MgO) and it can be used to directly mineralize CO2 from the atmosphere to produce magnesium carbonate ($MgCO_3$) using a different technique (Myers and Nakagaki, 2020). The negative CO_2 emissions brought upon by this direct mineralization process can be significant in combatting global warming. However, when extremely large amounts of $MgCO_3$ is produced, it is important to consider its feasible usage.

(a) Clay sand (b) Magnesium carbonate powder

Fig.1 Materials used in this study

In this study, usage of $MgCO_3$ as a geomaterial was considered by conducting a series of uniaxial compression tests on mixtures of $MgCO_3$ powder and another soil. However, this study was not conducted with standard testing procedures and apparatuses. Rather, it was done as a part of the SHIP course in 2020 AY, where SHIP is interactive class series for 1st-2nd year undergraduate international students at Waseda University (Cho et al. 2021). Due to COVID-19, a package including testing materials and simplified devices was delivered to each student to conduct tests and discussion on test results were made completely online. Five students, two TAs and two instructors were mainly involved in the group activities, and this paper introduces some results obtained by the first author.



(a) Material mixture (b) Fill mixture to the mould (c) Specimen compaction

(d) Compacted specimen (e) Place the specimen into the loading device (f) Apply loading until failure

Fig. 2 Specimen preparation process

2. Test procedure and programme

Two commercial materials, clay sand and $MgCO_3$ powder as shown in Fig.1, were used in this study. Basic physical properties of the two materials were not carefully measured, though it was known roughly that clay sand is a plastic silt and $MgCO_3$ powder should be non-plastic having hygroscopic property (Ropp 2013). Uniaxial compression tests were conducted on mixtures of the two materials by varying $MgCO_3$ powder contents from 0 wt% to 100 wt% with an interval of 10%. Additionally, for each case, five water contents from 10% to 30% with an interval of 5% were applied to prepare specimens. Specimen preparation procedure is shown in Fig. 2. A proper scale could not be provided in the package to measure material mass for mixing. Instead, spoons with different volumes were given, of which spoon volumes and material mass relations were calibrated for each material and with the calibration, mixtures with a volume of 50 ml for each testing condition was prepared. After adding predetermined amount of water and mixing thoroughly, the mixture was placed into a acrylic split mould and compacted by three layers into a specimen with height of about 50 mm and diameter of about 25 mm (Fig. 2a-d). Then the specimen was placed into a simplified uniaxial loading apparatus and vertical loading, at increments of 1kg, was applied by placing books on the loading plate of the apparatus until specimen failure (Fig. 2e-f). Note that a scale with capacity of 10 kg was provided in the package to measure book mass. The form of specimen failure might be slight cracks, shape deformation or collapse. As a very important factor, compaction energy was kept constant intuitively by lifting the compaction bar to the same height and applying the same number of blows for each layer. The load at which the specimen failed was used to calculate unconfined compressive strength of the specimen (q_u).

3. Results and discussion

The relations between water content and q_u for all tested cases are depicted in Fig. 3. It can be seen that the relations for cases with $MgCO_3$ ratio up to 30% are very similar to compaction curves with optimum water contents, at which q_u reaches maximum values. Though specimen dry density could not be measured, it can be expected that dry density of the specimen with maximum q_u should be close to maximum dry density of compaction curves. For cases with relatively lower $MgCO_3$ ratios (i.e. 10%-30%), the specimens showed q_u at water contents of about 25%, which is similarly observed in the 0% $MgCO_3$ case (i.e. pure clay sand case). However, as $MgCO_3$ ratio increases up to 60%, water content corresponding to maximum q_u moves to about 30% in the tested range. This implies that the $MgCO_3$ powder used in the study may have a finer particle size or higher water absorption ability compared to that of the clay sand. When $MgCO_3$ ratio further increase to 100%, the relations become irregular (i.e. without apparent maxima). And the overall trend for all eleven cases shows that q_u reduces as $MgCO_3$ ratio increases. This is also expected since clay sand is plastic and $MgCO_3$ powder is a non-plastic material, hence reducing soil sample cohesion as $MgCO_3$ ratio increases.

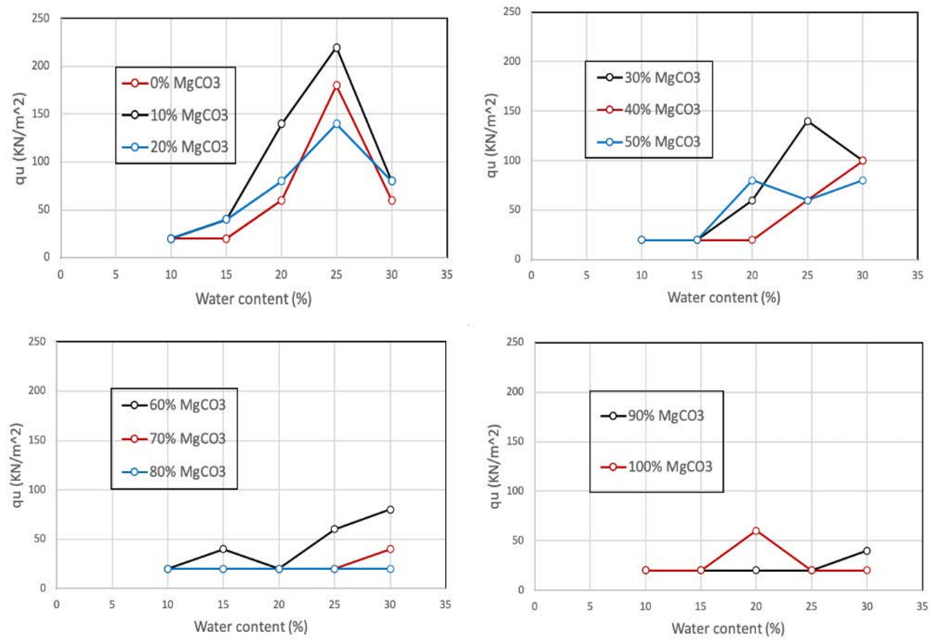


Fig. 3 Relations between water content and unconfined compressive strength (q_u) for mixtures with different $MgCO_3$ contents

For results in Fig.3, it can be seen that it would not very difficult to use $MgCO_3$ as a geomaterial and it may also have a potential of absorbing more water, which can be used to treat soft grounds. On the other hand, if CO_2 mineralization can be a second priority, MgO may be used to treat soils in a similar fashion as CaO, by which the process of forming $MgCO_3$ in the treated ground may also be strengthened in terms of cementation effect. However, applications of $MgCO_3$ or MgO, are of a precondition of negative CO_2 emissions in the whole process. That is, a life cycle assessment (LCA) has to be performed to see net CO_2 emission of the use of the $MgCO_3$ as a geomaterial. More detailed and rigorous tests will be conducted in the further study.

Conclusion

A preliminary study on usage of $MgCO_3$ as a geomaterial was conducted as part of a class for 2nd year undergraduate international students at Waseda University. The results obtained from this study suggest that the addition of the $MgCO_3$ powder to soils may be not very difficult when $MgCO_3$ ratio is relatively low. It was observed that the optimum water content of the sample increases when $MgCO_3$ ratio increases. Additionally, unconfined compressive strength (q_u) decreased upon an increase in $MgCO_3$ ratio. From all observations, it can be concluded that usage of $MgCO_3$ as a geomaterial may not be tough and it may also have a potential to increase ground strength by absorbing water in the ground.

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