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# Engineering properties of carbonated reactive magnesia-stabilized silt under different activity index

Liu Song-Yu[a], Cai Guang-Hua[a]*, Du Yan-Jun[a], Zhu Heng[b], Wang Ping[b]

[a]*Institute of Geotechnical Engineering, Southeast University, Nanjing, 210096, China.*
[b]*Nanjing Dong Da Geotechnical Engineering Technology Co. LTD, Nanjing, 210018, China.*

**Abstract**

Engineering properties of soft soils can gain great improvement through the addition of reactive magnesia (MgO) and further carbonation of substantial gaseous $CO_2$ absorbed. The paper studies the influence of MgO activity index on engineering properties of the carbonated silt with different water-MgO ratio. The engineering properties are investigated mainly through unconfined compression tests, and then the strength development are explained by the scanning electron microscopy (SEM). The results demonstrate that the mechanical properties of carbonated MgO-stabilized soils were greatly influenced by MgO activity index and water-MgO ratio, and the unconfined compressive strength of reactive MgO-stabilized soil has increased obviously after $CO_2$ carbonation. With increasing MgO activity index and reducing water-MgO ratio, the unconfined compressive strength increased, and the failure mode of carbonated specimens approximately changes from elastic-plastic to brittleness as well as their failure strain mainly ranges between 0.5% and 2.3%. The deformation modulus of carbonated silt generally increases with increasing unconfined compressive strength, and the ratio of the deformation modulus to unconfined compressive strength is about 35 to 150. A simplified equation with combining MgO activity index and water-MgO ratio is proposed for accurately predicting the unconfined compressive strength of carbonated MgO-stabilized soils. Moreover, the microstructural characteristics explain the strength gain of carbonated MgO-stabilized soils.


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*Keywords:* reactive magnesia; activity index; soft soil; carbonation; engineering properties.

* Corresponding author. Tel.: +86-025-83795086; fax: +86-025-83795086.
*E-mail address:* caiguanghua@seu.edu.cn


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## 1. Introduction

Foundation reinforcement, in which the native soils are generally mixed with various cementitious materials such as Portland cement (PC) and lime, have been extensively utilized in treating the soft soils existing in the construction of infrastructure projects [1, 2]. However, the strength gain of PC-stabilized soil is relatively slow due to the time-dependent formation of hydration products [3]. Moreover, the PC production involves intensive energy consumption and severe environmental impacts (~0.85 to 0.95 t $CO_2$/t PC and ~5% to 8% of global anthropogenic $CO_2$ emissions). Considerable efforts have been made to explore alternative low-carbon materials to completely or partially eliminate the use of PC, including supplementary materials such as fly ash and slag [4], geopolymers [5] and calcium carbide residues [6]. In recent years, reactive magnesia (MgO) cements were also put forward to be as one such alternative material owing to their higher hydration rate and greater potential in absorbing $CO_2$ [7]. Therefore, a prospective technology, in which reactive MgO was mixed with soil and then the mixture was exposed to $CO_2$ for carbonation, could generate the rapid and significant enhancement of soil strength as well as absorb lots of $CO_2$ [8]. Furthermore, reactive MgO is prone to hydrate to form brucite, which could then react with $CO_2$ and additional water to form a series of hydrated magnesium carbonates (e.g., nesquehonite, dypingite and hydromagnesite), which have been confirmed to possess significant advantages in strength growth and pore filling of untreated soils or reactive MgO-stabilized soils [9, 10].

Previous studies [11, 12] elucidated that MgO reactivity had a significant influence on the hydration kinetics of slags, and higher reactivity would result in a higher hydration rate, producing a larger quantity of hydration products and higher strength as a consequence. Mo et al. [13] studied the influence of the MgO reactivity on the deformation and mechanical properties of the MgO expansive cements. The MgO reactivity is generally measured according to the kinetic analysis method by determining the discoloration time of acidic solution used in the test, which qualitatively reflects the hydration rate of reactive MgO [11]. The Chinese Industry Standard [14] presented a method for measuring the MgO activity content or activity index ($c_A$, %) which can be calculated by using the equation (2).

$$c_A = \frac{40 \cdot (m_2 - m_1)}{18 \cdot m_1} \times 100\% \tag{1}$$

where $m_1$ and $m_2$ represent the dry mass of sample before and after hydration (g), respectively; 18 and 40 are the molecular weight of $H_2O$ and MgO (g/mol), respectively.

Previous studies [11, 12] have also indicated that the water-MgO ratio ($w_0/c$) and MgO activity index ($c_A$) significantly controlled the mechanical properties of carbonated reactive MgO-stabilized soils. However, very limited studies have been conducted to investigate the influence of MgO activity index on their engineering characteristics. This study aims at (*i*) investigating the influence of MgO activity index on the stress-strain characteristics, unconfined compressive strength and deformation modulus of carbonated soils, and (*ii*) proposing an empirical equation for quantifying the relation of the unconfined compressive strength to MgO activity index and water-MgO ratio.

## 2. Materials and Methods

### *2.1. Materials*

The soil used in this study was sampled from a highway construction site at 2.0 m depth in Suqian City, Jiangsu Province, China (see Fig. 1(a)). The basic physicochemical properties of the soil are shown in Table 1. Two types of reactive MgO powders, MgO-H (denoted as H) and MgO-L (denoted as L), were used in this study (Fig. 1(b, c)). MgO-H was light-burned white MgO powder with higher activity content from Xingtai City, Hebei Province, China; and MgO-L was heavy-burned light pink MgO powder with lower activity content from Haicheng City, Liaoning Province, China. The grain size distribution of materials was determined using a laser particle size analyzer Mastersizer 2000, and the particle size distribution curves were shown in Fig. 2. Moreover, the oxides of