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Influence of calcite particles on mechanical properties of grouted sandy soil

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Abstract

Chemical and mineralogical content of sands has very high influence on uniaxial compressed strength of grouted soils. In this paper influence of calcite particles in sand on mechanical properties of grouted with urea-formaldehyde resin sandy soil is described. Long-lasting experimental laboratory investigations are executed. In result of our investigations we make conclusion, that addition of calcite particles in sandy soil decreased compressed strength of grouted soil specimens observed in time of 3 months.

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Keywords: Sand; Soil stabilization; Calcite; Injection; Urea-formaldehyde resin; Compressive strength; Laboratory test.

1. Introduction

Calcite is a calcium carbonate mineral with chemical formula $CaCO_3$. It has the position 3 in classical Mohs scale of mineral hardness. Calcite is the basic mineral in metamorphic rock marble and in sedimentary rock limestone. It occurs in rock caverns as stalactites and stalagmites. Calcite may also be found in igneous rocks such as carbonatites or kimberlites. Its crystals are trigonal-rhombohedral [1]. Calcite will dissolve with hydrochloric acid HCl and with most other forms of acid. Calcite can be dissolved or precipitated by groundwater, depending on various factors including the water temperature and pH (numeric scale used to specify the acidity or basicity of an aqueous solution).

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Microbiologically precipitated calcite has a wide range of adaptations, such as soil remediation and soil stabilization [2]. Microbial-induced calcite precipitation (MICP) is a modern ground improvement method to increase strength and stiffness of sand using natural biogeochemical processes [3]. Two important factors of MICP are cementation level and confining pressure.

MICP is a promising technique for modifying physical and mechanical characteristics of the soil [4]. These modifications represent the requirements of some geotechnical and environmental applications. A bio-mediated cementation process improves the geotechnical properties of soils through the precipitation of calcite at soil particle contacts [5]. MICP method utilizes the metabolic pathways of bacteria to form calcite precipitation throughout the soil matrix [6].

In the event of hurricane, coastal regions of Atlantic and Pacific oceans are highly vulnerable. The erosion on coastal sand dunes can be devastating and may result in damage to structures. This damage can be real costly. The strength of loose, water saturated clean fine coastal sand increases by utilizing microbial-induced carbonate precipitation with injecting the reagents of ureolytic bacteria, urea and calcium [7,8].

Microbial induced calcite precipitation has advanced rapidly in the past ten years. However, its application as a prevalent ground improvement technique has been sometimes limited by the need for cultivation and injection of specific bacterial strains. The future of this environmentally clean technology is dependent on whether native bacteria can be stimulated to facilitate the precipitation of calcite [9].

Anderson with colleagues in 2014 investigated the application of microbial calcite with soil fibers to reduce the wind erosion potential, using a common soil bacterium, *Sporosarcina pasteurii*, mixed with medium containing urea $CO(NH_2)_2$ and calcium chloride $CaCl_2$. To increase the wind-erosion resistance, volume variations of the medium applied and soil preparation methods were examined. Significant reduction in mass loss as compared with that of the untreated sand has been observed [10].

Mechanical behavior of microbial-induced cemented sand was numerical investigated by Feng and colleagues in 2014 [11]. Sidik with colleagues in 2014 and 2015 analyzed effect of bio-cementation technology on permeability, compressibility and shear strength of organic soil [12,13].

Calcite in-situ precipitation system (CIPS) has been created as a permeation grouting system based on a two component fluid with the intention of slowly permeate and fill the pores. It causes cementation through a chemical reaction which bonds the soil particles together at the contact points. Calcite in-situ precipitation system mimics one of the natural reactions in nature where sandstone is formed through calcite precipitation. This system is used in Australia with positive results [14].

Sand is sedimentary rock and a natural granular material composed of divided mineral particles. It is defined by size. Sand can also refer to a textural class of soil [15]. The composition of sand varies, but the most common constituent of sand in continental and coastal settings is quartz. The second most common type of sand is calcium carbonate, for example calcite.

Calcareous sand is soil containing free calcium carbonate $CaCO_3$ and other carbonates to effervesce when treated with hydrochloric acid HCl solution [16].

By soil stabilization with injection technique is very important chemical and mineralogical content of grouted soil. It is very good investigated sandy soil stabilization with organic polymer solutions, but analyzed sand was in many cases clean, not calcareous in point content of carbonates.

We have intention to make laboratory test with grouted sand for determination the influence of calcite particles addition to traditional, no carbonated sand. We know that, for example, uniaxial compressive strength of specimens by jet grouting technique is less in organic soils that in clean sandy soils, but by jet grouting is used cement grout, not multi-molecular chemical solutions. In our case for soil stabilization experimental investigations is applied synthetic urea-formaldehyde resin.

2. Laboratory investigations for determination of calcite particles influence on properties of grouted sand

Urea-formaldehyde resin as stabilized agent for dispersive sandy soil was used. Iron chloride $FeCl_3$ as hardener was applied. Calcite particles for addition to fine quartz sand were crushed and sieved through 0.25 mm sieve for addition to fine quartz sand.

Specimens of sand stabilized with urea-formaldehyde resin solution were 4.5 cm high and 3.0 cm wide. Uniaxial compressive strength of these specimens was investigated after 7 days, 28 days and 90 days. Specimens were located all this time in air-moisture and water medium in room temperature.

For determination of crushed calcite particles addition influence on sandy soil properties were 5 sandy soil compositions investigated (Table 1).

Table 1. Compositions of sand specimens.

Name of sand composition for specimen	Quartz sand (*g*)	Calcite (*g*)
Composition "0"	100	0
Composition "5"	95	5
Composition "10"	90	10
Composition "15"	85	15
Composition "20"	80	20

Gel formation time of urea-formaldehyde resin solution (density 1.13 g/cm^3) with hardener 18 % iron chloride solution was 50 min in temperature of 20 °C. Proportion between urea-formaldehyde resin solution and hardener solution was 25:1.

For experimental laboratory investigation was made 6 specimens of each composition for each time in each medium. Average of compressive strength dimension by hardening of specimens in air-moisture medium is given in Table 2.

Table 2. Compressive strength of specimens in air-moisture medium (MPa).

Composition and time	After 7 days	After 28 days	After 90 days
Sand composition "0"	3.0	3.4	3.6
Sand composition "5"	2.6	2.8	2.8
Sand composition "10"	2.0	2.5	2.6
Sand composition "15"	1.3	1.7	1.7
Sand composition "20"	0.8	1.0	1.1

Average of compressive strength dimension by hardening of specimens in water medium is given in Table 3.

Table 3. Compressive strength of specimens in water medium (MPa).

Composition and time	After 7 days	After 28 days	After 90 days
Sand composition "0"	3.2	3.6	3.7
Sand composition "5"	2.6	2.9	3.1
Sand composition "10"	2.1	2.7	2.7
Sand composition "15"	1.5	1.7	1.9
Sand composition "20"	1.0	1.1	1.1

In all investigation stages was tested 180 specimens of stabilized sandy soil with various quantity of calcite additions.

3. Conclusions

1. Calcite in grouted soil can have a different impact. As component of microbial-induced calcite precipitation he increased stability of sandy soil. As component of sandy soil, with the most common constituent quartz particles, calcite decrease compressive strength of sand stabilized with urea-formaldehyde resins.

2. Decrease of compressive strength of grouted sand specimens is similar in air-moisture and water media.

3. Compressive strength of specimens increases with time up to 20 %, but specimens with addition of calcite increase time-dependent less. Increase is no dependent of media in which specimens hardened.

4. Sand composition “20”stabilized with urea-formaldehyde resin is more fitted for waterproofing layer than for strengthened structure.

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