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Thermo-mechanical behaviour of microbial induced carbonate precipitation (MICP) sand for geothermal pavements

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Introduction

Ground source heat pump (GSHP) or shallow geothermal energy systems are gaining attention for helping combat global warming and the negative effects of urbanisation caused by human activities. In recent decades, energy geo-structure techniques have developed by using subsurface infrastructures to exchange heat with the ground. These techniques can provide space heating and cooling while still preserving the primary structural function. As a result, they have become a valuable part of geothermal energy systems. Researchers have developed an understanding of incorporating ground heat exchangers into foundation piles, retaining walls, and tunnel linings with modest additional cost [1-4]. Pavements are also structures in contact with the ground that have the potential to be used as energy geo-structures (i.e., geothermal pavements), yet, their use has not been extensively studied [5-8].

Soil thermal conductivity is an important factor influencing the efficiency of geothermal pavements since heat transfer in soils occurs primarily by conduction [9]. Microbially induced calcium carbonate ($CaCO_3$) precipitation (MICP) is an innovative technique for strengthening sandy soils by coating and binding soil grains with calcium carbonate crystals. The distribution and arrangement of the $CaCO_3$ within the pore spaces play a crucial role in determining the resulting strength of the treated sand. In addition, these crystals can act as thermal bridges to enhance the soil's thermal conductivity [10]. Combining geothermal pavements with MICP sand is still nascent, and the limited number of studies that exist mainly focus on the associated thermal property changes [11]. However, since the principal function of pavements is transmitting (dynamic) loads to the subbase and the underlying soil, the thermal conductivity of the MICP-treated pavement may vary as a result of the applied mechanical loads (e.g., due to the partial or total loss of thermal bridges and/or particle rearrangement). This research thus investigates the changes in the thermal conductivity of MICP-treated sands as they are subjected to quasi-static triaxial compression. The experimental results collected can deepen our understanding of the thermo-mechanical behaviour of MICP-treated sands and provide practical insights for using MICP to reinforce the subbase or underlying soil of geothermal pavements.

Methodology

This research performed a series of quasi-static triaxial tests on MICP-treated Houston sand, fine-grained, high-purity silica sand. *Sporosarcina pasteurii* (strain designation DSM 33) was used for the MICP treatment of the soil specimen. To study the effect of $CaCO_3$ content on the thermo-mechanical performance of MICP-treated sand, three cementation solution treatment cycles were applied, yielding theoretical $CaCO_3$ contents of 0.6%, 1.6% and 2.7% by weight, respectively. Details on the MICP treatment of the samples can be found in [12]. Samples for triaxial testing were treated in cylindrical tubes of 50mm inner diameter and 100mm

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height. To investigate the influence of the $CaCO_3$ content on the soil thermal conductivity, MICP-treated specimens were air-dried prior to triaxial testing Triaxial tests were subsequently conducted in dry conditions to isolate the effect of the MICP and avoid the influence of water content on soil thermal conductivity (λ). Furthermore, a new miniaturised transient sensor was embedded in the triaxial samples to monitor the λ changes during the sharing phase [12].

Results

An example of the evolution of the deviatoric stress with axial strain under 50kPa confining stress (σ_3) in the triaxial cell is shown in Figure 1a. Compared to the untreated sand, MICP-treated samples lead to higher peak strength and stiffness. Importantly, λ changes during triaxial testing for different $CaCO_3$ contents are summarised in Figure 1b. Results indicate that the increase in $CaCO_3$ content can significantly improve λ, and that λ rapidly decreases post-peak strength due to dilation and $CaCO_3$ bond breakage. Once the samples reach its ultimate state, λ remains unchanged.

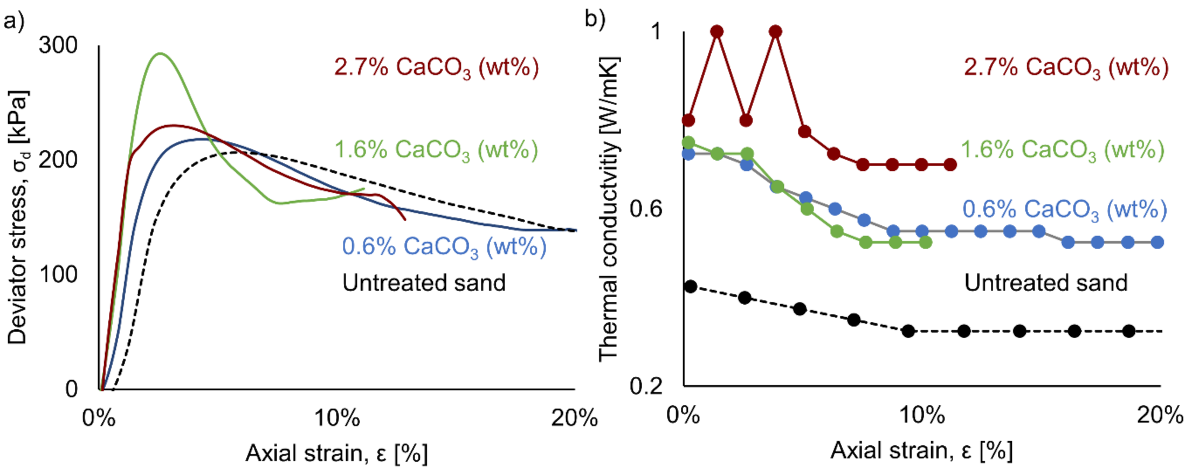

Figure 1 Key results: a) triaxial test results for MICP treated samples and untreated sand; b) Thermal conductivity evolution under triaxial shearing for MICP-treated sands versus axial strains.

Contributor statement

Xiaoying Gu: Conceptualisation, Data curation, Methodology, Software, Formal analysis, Investigation, Visualization, Writing - original draft. Alexandra Clarà Saracho, Nikolas Makasis, Monika Johanna Kreitmair, Stuart Haigh and Guillermo Narsilio: Conceptualisation, Supervision, Formal analysis, Visualisation, Writing - review & editing, funding acquisition.

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