“Investigation into microbial alteration of extraterrestrial regolith simulants for cementation and induced cohesion in support of NASA’s in-situ resource utilization efforts”

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AY [2020-2021] Progress Report

Background & Significance

Establishing a lunar outpost will pose new challenges from the lack of immediate access to supplies which has expanded geotechnical interests into viewing regolith as a resource. Bio-inspired geotechnics is an emerging research area and is in line with the NASA’s priorities of in-situ resource utilization to develop sustainable infrastructure. Microbially induced calcite precipitation (MICP) is a biomineralization process which introduces microbial populations within a porous media (e.g. lunar regolith) to precipitate calcium carbonate in the polymorph of calcite via urease hydrolysis. The precipitation of calcite can bond otherwise loose soil particles, thereby increasing the shear strength and stiffness of the soil while decreasing its permeability and compressibility. Although the bacteria would need to be introduced on extraterrestrial bodies, this technique has a strong potential to be used to increase shear strength and stiffness of a weak or unconsolidated regolith for slope stabilization, habitat construction, or even creating bricks.

Project Goals

The research objectives are to: Perform bench top studies to optimize calcite precipitation via urease hydrolysis and determine partitioning coefficients; Perform representative laboratory testing to determine the change in mechanical properties of regolith simulants at various levels of calcite precipitation; and develop novel biogeochemical sensors to monitor chemical reactions during MICP treatment.

Summary of Key Findings

Recent efforts have focused on the precipitation of calcite in aqueous and porous media, qualification and quantification of the precipitated calcite, development of novel biogeochemical sensors, and the design of a multi-functional testing apparatus for simultaneously measuring physical and chemical changes to a soil specimen during MICP treatment. The novel electrochemical, potentiometric biogeochemical sensors monitor key chemical and by-product concentrations of the MICP reaction. The characteristic chemical changes or by-products resulting from MICP are the production of the urease enzyme, reduction in Ca^{2+} ion concentration, reduction in H^+ ion concentration, and increase in NH_4^+ ion concentration. The latter two chemical changes are indicative of the enzymatic-driven decomposition of urea wherein there is an increase in pH and production of ammonium. The use of ion-selective membrane electrodes for real-time monitoring of MICP is attractive for their high sensitivity, low detection limit, and fast response time. Future efforts will focus on shear wave velocity measurements taken in tandem with biogeochemical sensor measurements. Shear wave velocity measurements on MICP-treated soil specimens in conjunction with biogeochemical sensor measurements should provide observations and correlations between measurable physical soil parameters (e.g. soil stiffness) and sensor measurements.

Representative data from ongoing work are included below and highlight: 1) SEM imaging of calcite precipitation (**Figs.1-2**), 2) treated and untreated glass beads using MICP to show efficacy in particle to particle bonding (**Fig.3**), and 3) the prototype design of a multi-functional testing apparatus for simultaneously measuring physical and chemical changes to a soil specimen during MICP treatment (**Fig.4**). The evolution of the MICP process is depicted in **Figs.1-3** which highlight the formation of calcite (**Fig.1**), the bonding or particle bridging of individual particles with calcite (**Fig.2**), and the effect the interparticle bonding of the otherwise loose particles has on the porous media (**Fig.3**).

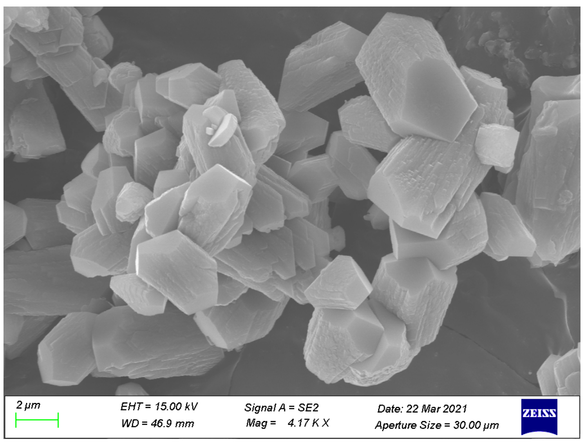

Figure 1. *SEM imaging of precipitated calcite.*

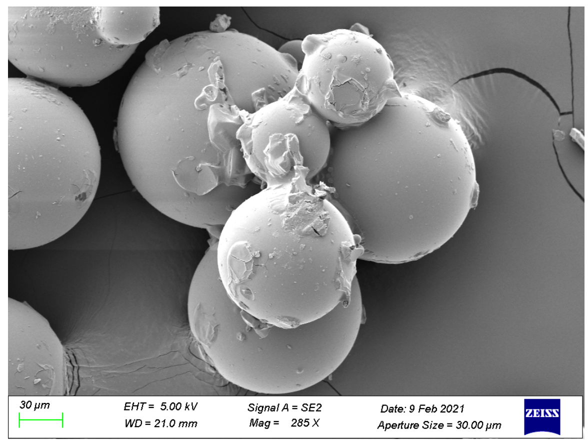

Figure 2. *SEM imaging of calcite bridging between glass beads.*

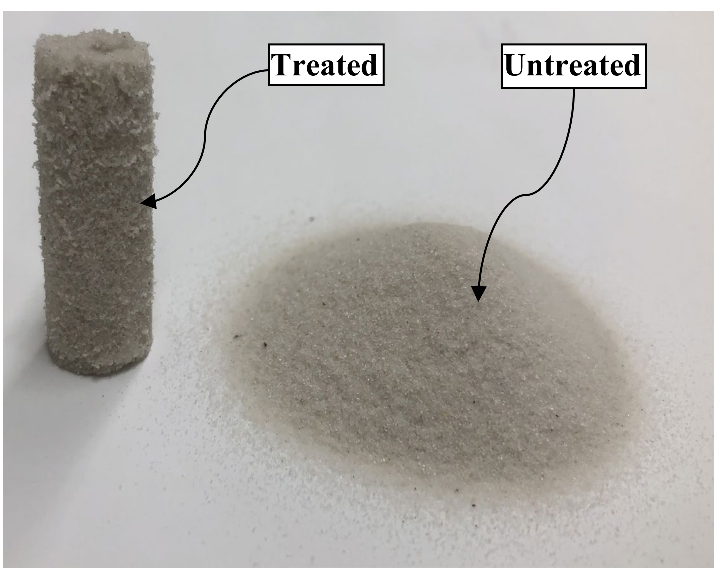

Figure 3. *Glass beads treated and untreated via MICP.*

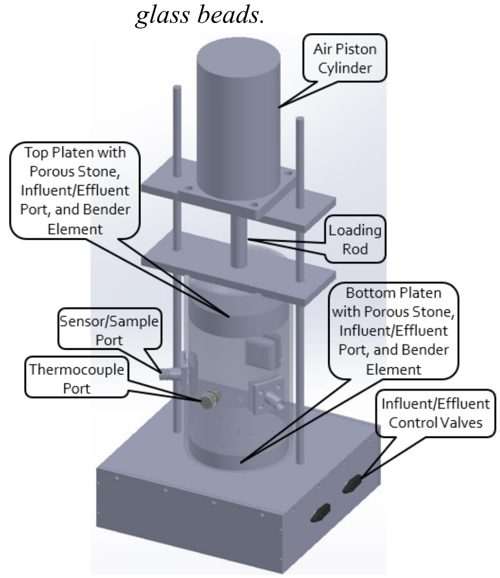

Figure 4. *Design of a multi-functional test apparatus for simultaneously measuring physical and chemical changes to a soil specimen during MICP treatment.*