Effect of Bacterial Strain on MICP and its Application for the Erosion Control of Fine Sands

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Abstract

Tangential flow-induced erosion poses a major threat to a wide variety of engineering structures, including earth-filled embankment dams and oil and gas extraction wells. Current mitigation solutions are limited to mechanical approaches (*e.g.* filters, gravel packs), relying on the fulfilment of a 'paradoxical permeability-retention criterion'; and to the use of emergency hydraulic head reduction which limits serviceability. In this context, microbial induced calcium carbonate ($CaCO_3$) precipitation (MICP) could be used to enhance the erosion performance of soils. This research investigates the influence of the $CaCO_3$ microstructure on the macromechanical erosion response of fine sands by combining instrumental techniques for characterisation, with element-scale flume testing and controlled modelling of a heterogeneous layered system.

The flume tests employed a newly designed Erosion Function Apparatus (EFA) and testing procedure to measure surface erosion, focusing on fine-coarse sand interfaces treated with the same soil bacterium (*Sporosarcina pasteurii*), but varying urea-$CaCl_2$ solution concentrations. The key aspect examined was the role of $CaCO_3$ micro-architecture–comprised of the $CaCO_3$ vertical profile, crystal size and distribution, and morphology. Results showed that higher $CaCO_3$ contents, bigger crystals, and cohesive bonds yield lower erodibility values. It was also seen that crystal growth mechanisms could change depending on bacterial distributions, urea-$CaCl_2$ solution concentrations, and the pore space of the original granular material.

As MICP moves from research into practice, the effect of bacterial strain on $CaCO_3$ precipitation also needs to be considered. The morphology, mineralogy and crystalline properties of biominerals precipitated by three different ureolytic microorganisms were henceforth investigated. These strains were: *S. pasteurii*, *S. aquimarina*, and *S. newyorkensis*–a newly isolated microbe from the Daini-Atsumi Knoll in offshore Japan. From *in vitro* experiments it was found that $CaCO_3$ polymorph selection can be controlled through selection of ureolytic strain with appropriate precipitation kinetics, and that metastable polymorph stabilisation is dependent on the kinetics of the mobile water contained within the crystal structure.

Finally, the Cambridge Plane-Strain Sand Production Apparatus (SPA), through the incorporation of Particle Image Velocimetry, was used to examine the effect of bacterial strain-specific MICP on the deformation mechanisms of a layered granular system resulting from lateral unloading due to erosion. It was observed that MICP treatment reduces sand production at the expense of ductility, however, this behaviour becomes more prominent with increasing $CaCO_3$ polymorph stability–namely, amorphous calcium carbonate (ACC), vaterite, and calcite. Correlations between microstructual characterisation, and EFA and SPA results highlighted the potential for designing bio-reinforced geo-materials that capitalise on the different $CaCO_3$ microstructural features.