Enzyme Induced Calcium Carbonate Precipitation and its Application

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***Abstract*— Efforts have been made in recent decades towards the development of sustainable ground improvement techniques. Although conventional ground improvement techniques have been used extensively, these methods are generally expensive. The use of biological processes, notably bio-cementation, for ground improvement is a relatively new area and a potentially sustainable alternative technique. Microbially induced calcium carbonate precipitation (MICP) and enzyme induced calcium carbonate precipitation (EICP) are the most widely studied bio-cementation techniques. EICP achieve soil improvement through calcium carbonate (CaCO3) precipitation facilitated by urease enzymes within a week. The precipitated CaCO3 binds soil particles, influencing some engineering properties of the soil, erosion resistance, dust control and removal of heavy metals.**

***Index Terms*— Biocementation, EICP, MICP, Urease enzyme**

I. INTRODUCTION

The need to accommodate a growing global population has become a major concern in many societies and has pushed human inventiveness to new levels. The demand for engineering solutions to enhance the mechanical qualities of the ground and generated concerns about the sustainability of engineering practices that heavily rely on energy-intensive materials and processes from the past. As conventional ground improvement techniques are generally expensive and often have very large energy and CO_2 footprints, the use of bio-cementation has found to be relatively new area and a potentially sustainable alternative technique. Microbially induced calcium carbonate precipitation (MICP) and enzyme induced calcium carbonate precipitation (EICP) are the most widely studied bio-cementation techniques which achieves soil improvement through calcium carbonate ($CaCO_3$) precipitation facilitated by urease enzymes produced by bacteria cells or plants, respectively.

Enzymatic ureolysis is catalyzed by the urease enzyme which hydrolyzes the urea ($CO(NH_2)_2$) into carbon dioxide (CO_2) and ammonia (NH_2).

$$CO(NH_2)_2 + 2H_2O \rightarrow 2NH_4^+ + CO_3^{2-} \quad (1)$$

$$CaCl_2 \rightarrow Ca^{2+} + 2Cl^- \quad (2)$$

$$Ca^{2+} + CO_3^{2-} + CaCO_3 \downarrow \text{(Precipitated)} \quad (3)$$

II. SOIL TREATMENT METHODS IN EICP

A. Mix and Compact Method

In this method, soil and the cementation solution (consisting of urea, calcium chloride, urease enzyme) are mixed to form a homogenous paste. The paste is then compacted in multiple layers and left to cure for several days (usually 7–14 days) in the mould.

B. Gravity Percolation Method

In this method, the soil sample is filled into the mould by compacting in multiple layers. A pre-determined volume of the cementation solution is poured from the top. The sample is kept for curing (usually 7-14 days) in the mould. In some cases, the urease enzyme is mixed with the dry soil and filled into the mould followed by percolation of cementation solution (containing urea-$CaCl_2$).

III. APPLICATIONS OF EICP

A. Soil Strengthening and Stabilization

[3] analysed the efficiency of enzyme-induced carbonate precipitation (EICP) on three different soil types (silty sands, clayey sand and silt). It was found that silty sand (SM) and clayey sand (SC) soils showed a considerable improvement in their unconfined compressive strength, whereas silt (ML) soil showed a less significant improvement. Compared to silty sand, clayey sand (SC) had a higher contact point for the

nucleation of calcite crystals and a superior ability to build effective connections between soil particles (SC). Further increases in silt's fine content (ML) improved the void ratio, which decreased the impacts of load transfer by reducing the number of calcite nucleation locations. [2] studied the influence of the soil type on the strength of the treated soil using different stabilization techniques. In order to reduce cement usage, the potential of combining EICP treatment with soil improvement using OPC was also investigated (and hence the carbon footprint). Three different local natural sand types from Saudi Arabia were used in the study, along with a standard sand (Ottawa 20/30 sand). Investigations were conducted on three different EICP cementing solution compositions. In addition, hybrid approaches that combined 10% OPC with an EICP cementing solution and various curing protocols were used to treat the soil. After one cycle of treatment, the sands stabilized with 10% OPC had a lower unconfined compressive strength than the sands treated with EICP. A microstructure analysis indicated that the addition of cement to the EICP treatment in the hybrid methods had a negative effect on the strength of the stabilized sand. This study demonstrated the efficacy of using the EICP biocementation process without mixing cement, protecting the environment from the negative consequences of cement manufacture.

B. Erosion Resistance and Dust Control

Conventional methods for fugitive dust control, are either ineffective in arid climates, very expensive, or limited to short-term stabilization. To assess the effectiveness of using EICP as a strategy to stabilize soil against fugitive dust emission, Knorr conducted wind tunnel tests at the ASU/NASA Planetary Wind Tunnel. Three diverse soil types namely a native silty sand of Arizona, a consistent fine- to medium-grained silica sand, and mine tailings from a mine in southern Arizona were investigated. In a specimen container, the test soil was placed loosely before being sprayed with an aqueous solution containing urea, calcium chloride, and urease enzyme. The specimens were examined in the wind tunnel after a brief amount of time to allow for $CaCO_3$ precipitation. It was found that EICP can increase the detachment velocity compared to bare or wetted soil and thus holds promise as a means of mitigating fugitive dust emissions. [5] conducted an experiment to evaluate the effect of including a hydrogel in the treatment solution on the performance of a wind erosion-resistant crust formed using EICP. Fine sand which is highly susceptible to wind erosion were treated by spraying their surface with a baseline EICP solution and with an EICP solution enhanced by the addition of xanthan gum hydrogel (XEICP). Treated samples were cured, saturated, and tested for bulk hydraulic conductivity. The bulk hydraulic conductivity was reduced from 2.01×10^{-2} cm/s for the untreated dry control specimen to 9.87×10^{-2} cm/s for the XEICP treated specimen. Water erosion testing indicated that XEICP treatment forms a crust more durable to water erosion than treatment with the EICP solution or with xanthan gum treatment alone.

C. Liquefaction Mitigation

[7] evaluated the applicability of the EICP technique for the mitigation of the liquefaction potential of Toyoura and Keisha No. 4 sands by means of series of undrained cyclic shear strength tests. Their findings indicated that soils treated with EICP had much better liquefaction resistance. Also [8] used EICP treatment methods to investigate the liquefaction resistance capabilities of silica sand. It was observed that the UCS strengths of the EICP treated sands were higher (272 kPa), indicating a greater potential to delay the beginning of soil liquefaction.

D. Removal of Heavy Metals

[4] examined the ability of crude extracts of Canavalia ensiformis to catalyze the precipitation of calcium carbonate ($CaCO_3$) in columns packed with heavy metal contaminated mine waste collected from an abandoned mine site. He also examined the effect of $CaCO_3$ precipitates on the leaching of heavy metals out of such waste. SEM and X-ray diffraction techniques were used to examine the morphology of the resultant material and confirm $CaCO_3$ precipitation. In column experiments, when the waste was treated with C. ensiformis crude extract it was observed that the amounts of the heavy metals As, Mn, Zn, Pb, Cr, and Cu in leachates from the mine waste were reduced by 31.7%, 65.7%, 52.3%, 53.8%, 55.2%, and 49.0%, respectively. This reduction can be attributed to the immobilization of heavy metals within the mine waste as a result of $CaCO_3$ precipitation. [2] explored swelling and permeability characteristics of two native Indian cohesive soils

(Black and Red). Inorder to understand the sorptive response of the heavy metals sorption and desorption of multiple heavy metals (Cd, Ni and Pb) onto these soils were conducted. The selected soils were treated with different enzyme solutions to improve the heavy metal retention capacity and enhance swelling and permeability characteristics. The results showed that calcium carbonate ($CaCO_3$) precipitate deposited in the voids of soil has the potential to reduce the permeability of soil up to 47-fold and swelling pressure by 4-fold at the end of 21 days of curing period.

IV. CONCLUSIONS

EICP was found to be an effective method for strengthening and stabilization of soil, erosion resistance and dust control, liquefaction mitigation, removal of heavy metals. The findings from this study suggest that the EICP technique has many potential applications in civil and geotechnical engineering, particularly in fine-grained soils such as silt or clay. To be practically and economically applicable under field conditions, various aspects such as in-situ treatment approaches, durability over time, costs and sustainability considerations need to be considered.

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