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An Overview of Microbial Induced Calcite Precipitation in Soil Improvement

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Abstract – *The various methods are in practiced for improving the properties of soil such as flyash stabilization, cement stabilization, lime stabilization, chemical stabilizers have an adverse effect on the environment and economy. Mechanical stabilization could have been a reasonable alternative; however, these techniques consume more energy with little economic benefit. Hence, researchers are in search of a sustainable alternative to overcome these drawbacks. Hence, Microbial Induced Calcium Carbonate Precipitation (MICP) is an eco-friendly and sustainable alternative where microbes play a major role to strengthen soils by precipitating calcium carbonate. . This paper aims to study of different microbial, their microbiological processes and their geotechnical applications to enhance the properties of soil. The microbial enhances the shear strength while it reduces permeability and settlements of soil. The microbiological processes include calcite precipitation, mineral transformation and different pathways. The bio-clogging and bio-cementation will enhance the properties of cohesionless soil. This paper review, the geotechnical applications of cementation of sands to enhance bearing capacity and liquefaction resistance, sequestration of carbon, soil erosion control, groundwater flow control, and remediation of soil.*

Keywords- *MICP, Bioclogging, Biocementation*

INTRODUCTION

In recent years, use of Microbial Induced Calcite Precipitation technique is to alter the engineering properties, is gaining attention as a versatile and green method of soil improvement. When a soil is treated using MICP technique, microbial induced calcite bridges adjacent soil particles, cementing soil particles together. The precipitation of calcite between particle-particle also helps in reducing the permeability, compressibility and increasing soil strength. Calcite mineralization can occur as a by-product of microbial metabolic activity such as photosynthesis, urea hydrolysis, sulfate reduction and iron reduction. During these different metabolic processes, the alkalinity or pH of the system increases, favoring the calcite precipitation. The MICP process regulated mainly by four key factors (i) concentration of calcium ion (ii) concentration of dissolved inorganic carbon (iii) pH (iv)availability of nucleation sites. In addition, several environmental parameters such as salinity, temperature, geometric compatibility of bacteria etc. may also govern performance of calcite precipitation (Ng-Wei Soon 2014).

MICROBIALLY INDUCED CARBONATE PRECIPITATION

Microbially induced carbonate precipitation (MICP) gained interest in the last 20 years, in particular with regard to the potential application of soil improvement and decayed ornamental stone production. Microorganisms can influence calcium carbonate precipitation by changing almost all the parameters described above. Mainly four groups of microorganisms are seen to be involved in the process

(i) Photosynthetic organisms — such as cyanobacteria and algae
(ii) Sulphate reducing bacteria — that are responsible for dissimilatory reduction of sulphates
(iii) Organisms utilizing organic acids
(iv) Organisms that are involved in the nitrogen cycle either ammonification of amino acids/ nitrate reduction/ hydrolysis of urea (Stocks-Fischer et al., 1999)

TYPE OF BACTERIA

The type of bacteria is essential for urease production, and therefore, many bacteria with ureasic activity have been studied; however, strains of the Bacillus group are the most commonly used in MICP. For example, S. pasteurii has been used for remediation, heavy metal contamination, concrete remediation and soil improvement (Li, Chen & Burne, 2013; Whiffin, van Paassen & Harkes, 2007, Dhami et al., 2014; Soon, Lee, Khun, & Ling, 2013, Sandra Patricia Chaparro-Acuña 2018).

MICROBIOLOGICAL MECHANISM

The mechanisms for microbiological applications to geotechnical engineering can be divided into two main categories: bioclogging and biocementation. Bioclogging is a process where the soil void is filled by the product from microbial-induced biochemical process. Biocementation is to enhance the strength and stiffness properties of sand and rocks by introducing bacteria and cementation reagents into the soil. Microbial Cementation mechanism as shown in Fig. 1.

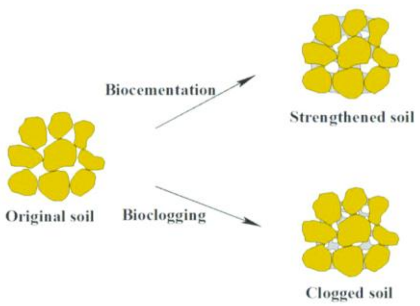

Fig. 1 - Cementation Mechanism of Bio-cement

Permeability

Van Paassen (2009) reported 60% reduction in the initial permeability of biotreated soils at approximately 100 kg/m^3 $CaCO_3$ precipitation, whereas Ivanov et al. (2010) recorded a permeability reduction of 50–99% using 1 M cementation solution. Al Qabany and Soga (2013) used 0. 5 M cementation solution and found a reduction of 20% in the initial permeability value at 2% $CaCO_3$ precipitation. Ivanov and Chu (2008) introduced the concept of bioclogging, by filling the pores with the cementing agent ($CaCO_3$) derived from bacteria. Their results showed a significant permeability reduction (5×10^{-5} m/s to 1.4×10^{-7} m/s).

Porosity

Porosity is the amount of voids in a material. Victoria et al. (2007) characterized the effectiveness of cementation in terms of the porosity of cemented sand samples and its reduction, and found that the porosity was decreased to 90% after MICP treatment. Tagliaferri et al. (2011) used X-ray imaging and quantitative a 3D digital image analysis to analyze the crushed biocemented bonds and found that the overall porosity of biocemented soil was reduced to 30%.

Stiffness

It was found that the strength and stiffness of cemented materials increase with the increase of the amount of cementing material in the soil matrix Rahim et al. (2014) and Montoya and DeJong (2015) studied the effect of biocementation on stress–strain behavior of biotreated sand and found that the stiffness was greatly improved with the increase of MICP cementation (i.e. $CaCO_3$ content).

Shear Strength

Shear strength is the magnitude of shear stress that a soil can sustain and depends strictly on the shear strength parameters of soil including the cohesion (c) and friction angle (Φ). Montoya and DeJong (2015) observed that the shear strength of MICP treated sand was dramatically improved with the increase in MICP cementation. Cheng et al. (2013) also discussed the cohesion and friction angle of biocemented soil samples treated under different degrees of saturation and showed that at lower saturation degree, the precipitated $CaCO_3$ crystals contributed more to improving the soil cohesion than the friction angle. In contrast, Chou et al. (2011) reported a large increase in soil friction angle but a small increase in soil cohesion was detected for almost all treated samples using MICP which was catalyzed by three conditions of Sporosarcina pasteurii (growing, resting and dead cells).

Unconfined Compressive Strength (UCS)

The unconfined compressive strength (UCS) is the most commonly used test to describe the strength of biocemented soils, as reported by many researchers (Cheng et al. 2013; Harkes et al. 2010; Ivanov et al. 2015; Whiffin et al. 2007; Zhao et al. 2014). Available results in the literature reported that the lowest recorded UCS value was 150 kPa, whereas the highest value was 34 MPa, at different MICP treatments (Whiffin 2004). Yasuhara et al. (2011) used the enzyme of urease to induce calcite precipitation and they found the UCS of urease-treated sand in the range of 400–1,600 kPa. Rahim et al. reported that greater improvement in UCS was achieved (50 to 240 kPa)

Microstructure

Cheng et al. (2013) found that not all $CaCO_3$ crystals precipitated in the sand pores necessarily contribute to the shear strength of biocemented soil but rather the crystals forming the effective bridges that link the sand grains together at the inter-particle level. DeJong et al. (2010) presented a clear explanation in relation to the distribution alternatives of $CaCO_3$ precipitation within the pore spaces, as shown in Fig. 2. This includes the "uniform" distribution which means an equal thickness of $CaCO_3$ precipitation around the soil particles, producing a relatively small bonding between the sand grains, and "preferential" distribution which indicates the particle to particle contacts of $CaCO_3$ precipitation at which the $CaCO_3$ crystals contribute to the soil improvement. Fig. 3 shows a schematic diagram of the above mentioned two different $CaCO_3$ distributions within the soil pore spaces.

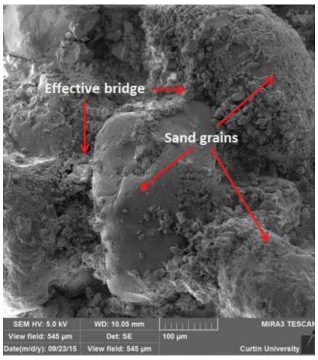

Fig. 2-Scanning electron microscopy (SEM) image showing the effective bridge formation.

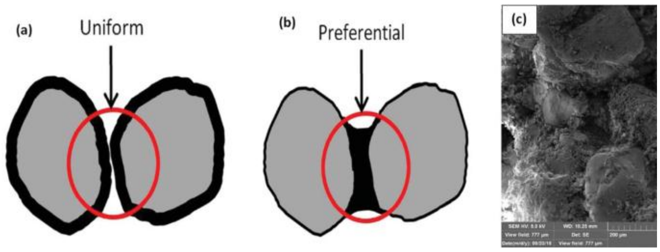

Fig. 3-Different CaCO3 distribution within the pore spaces: (a) uniform; (b) preferential distributions (DeJong et al. 2010); and (c) actual distribution.

APPLICATIONS OF MICROBIAL IN GEOTECHNICAL ENGINEERING (Wath and Pusadkar, 2016)

The microbial can be widely used in soil improvement in various ways. In most of process injection mode can be used for bacteria intrusion while in some cases mixing with soil can be taken place before placing in position. Some of the areas where improvement needs are,

- Reinforcing or stabilizing soil to facilitate the stability of tunnels or underground constructions;
- Increasing the bearing capacity of piled or non-piled foundations;
- Reducing the liquefaction potential of soil;
- Treating pavement surface;
- Strengthening tailings dams to prevent erosion and slope failure;
- Binding of the dust particles on exposed surfaces to reduce dust levels;
- Increasing the resistance of offshore structures to erosion of sediment within or beneath gravity foundations and pipelines;
- Stabilizing pollutants from soil by the binding;
- Controlling erosion in coastal area and rivers

CONCLUSION

- MICP treatment has high potential for improving the engineering, mechanical and physical properties of biocemented sand.
- The envisioned applications of MICP have self-healing of soil, slope stabilization, settlement reduction and erosion control as well as liquefaction prevention.
- Urea hydrolysis is the most preferred $CaCO_3$ precipitation mechanism because it can be easily controlled and possesses about 90% of $CaCO_3$ production efficiency in a short period of time.
- The use of microbials for improvement of soil characteristics is not only very cost effective method but also eco-friendly method.
- It is required to observe the performance of microbial treated soil in field or real engineering problem.
- It will also need to ensure the retention capacity, environmental effect of gained strength and lifelong serviceability.

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