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Sand Solidification through Microbially Induced Carbonate Precipitation for Erosion Control: Prospects in Bangladesh

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Abstract

Bio-cementation is a sand consolidation technology, in which ureolytic bacteria release carbonate from urea hydrolysis in the presence of an excess of calcium ions to form calcite ($CaCO_3$) in-situ. Biocementation is to enhance the strength and stiffness properties of soil and rocks though microbial activity or products. This paper addressed the prospect of microbial carbonate precipitation for erosion control in Bangladesh. Bacterial $CaCO_3$ precipitation under appropriate conditions is a general phenomenon where the ureolytic bacteria uses urea as an energy source and produces ammonia which increases the pH in the environment and generates carbonate, causing Ca^{2+} and CO_3^{2-} to be precipitated as $CaCO_3$. This $CaCO_3$ join sand particles and forms rocklike materials that auto-repairs by means of sunlight, seawater, and bacteria as microbially induced carbonate precipitation method. These rock particles when produced artificially is called artificial rock and has the potentiality to protect coastlines from erosion.

Key words: Bio-cementation, Carbonate precipitation, Erosion

Introduction

Microbial geotechnology is an emerging branch of Geotechnical Engineering. As the scale of geotechnical construction such as land reclamation is usually large, a microbial treatment could be one of the most cost effective methods. The major factors that affect the applications of microorganisms to geotechnical engineering include the screening and identification of suitable microorganisms for different applications and different environments, the optimization of microbial activity in situ, biosafety of the application, cost effectiveness, and stability of soil properties after biomodification (Ivanov and Chu, 2008). Among all the factors, cost effectiveness is the most important factor for large-scale application.

Biocementation is to enhance the strength and stiffness properties of soil and rocks though microbial activity or products. It could be used to prevent soil avalanching, reduce the swelling potential of clayey soil, mitigate the liquefaction potential of sand, and compact soil on reclaimed land sites (Ivanov and Chu, 2008). Traditional grouting methods for ground improvement employ particulate (cement/bentonite) or chemical grouts that can be rather expensive and environmentally unfriendly (Ivanov and Chu, 2008). Recently, novel grouting techniques have been developed to treat unsaturated coarse-soils by stimulating natural processes (DeJong *et al.*, 2006; Whiffin *et al.*, 2007). One of these methods, termed biogrouting, has shown some promise in soil cementation via Microbially Induced Carbonate Precipitation (MICP). This approach mimics natural processes by depositing calcite ($CaCO_3$) on the soil grains, thereby increasing the material's stiffness/strength and reducing its erodibility.

In ground treatment applications for sandy soil, the deposition of calcite over the grain surfaces and around the grain contacts creates a sandstone-like material. In principle, MICP treatment protocols can be tailored to produce a more targeted deposition of calcite around the grain contacts, with the porosity decreasing by less than 10% (Shahrokhi-Shahraki *et al.*, 2014). Hence, significant improvements in the geomechanical properties can be achieved while maintaining permeability. Present paper addressed the prospect of microbial carbonate precipitation for erosion control in Bangladesh.

Microbially induced carbonate precipitation (MICP)

Like other biomineralization processes, $CaCO_3$ precipitation can occur by two different mechanisms: biologically controlled or induced (Lowenstan and Weiner, 1988). In biologically controlled mineralization, the organism controls the process, i.e. nucleation and growth of the mineral particles, to a high degree. The organism synthesizes minerals in a form that is unique to that species, independently of environmental conditions. Examples of controlled mineralization are magnetite formation in magnetotactic bacteria (Bazylinski *et al.* 2007) and silica deposition in the unicellular algae coccolithophoresand diatoms, respectively (Barabesi *et al.*, 2007). However, calcium carbonate production by bacteria is generally regarded as "induced", as the type of mineral produced is largely dependent on the environmental conditions (Rivadeneyra *et al.*, 1994) and no specialized structures or specific molecular mechanism are thought to be involved (Barabesi *et al.*, 2007). Different types of bacteria, as well as abiotic factors (salinity and composition of the medium) seem to contribute in a variety of ways to calcium carbonate precipitation in a wide range of different environments.

This approach mimics natural processes by depositing calcite ($CaCO_3$) on the soil grains, thereby increasing the material's stiffness/strength and reducing its erodibility. The microbiological process relies on ureolytic (non-pathogenic) bacteria such as *Sporosarcina pasteurii* or *Bacillus pasteurii* to hydrolyse urea in the presence of calcium ions, resulting in the precipitation of calcite crystals.

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

$$Ca^{2+} + CO_3^{2-} \xrightarrow{yields} CaCO_3\ (s) \quad (2)$$

The actual role of the bacterial precipitation remains, however, a matter of debate. Some authors believe this precipitation to be an unwanted and accidental by-product of the metabolism (Knorre and Krumbein, 2000) while others think that it is a specific processwith ecological benefits for the precipitating organisms (Ehrlich, 1996; McConnaughey and Whelan, 1997).

Cementation process through bacterial action

Bacterial $CaCO_3$ precipitation under appropriate conditions is a general phenomenon (Bouquet *et al.*, 1973). There are a number of species of $CaCO_3$ minerals associated with bacteria, for example vaterite formation by *Acinobacter* sp. (Sanchez-Moral *et al.*, 2003), aragonitic sherulites by Deleyahlophila (Rivadeneyra *et al.*, 1996), calcite by *E. coli* (Bachmeier *et al.*, 2002). The ureolytic bacteria uses urea as an energy source and produces ammonia which increases the pH in the environment and generates carbonate, causing Ca^{2+} and CO_3^{2-} to be precipitated as $CaCO_3$ (Eq. 6- Eq. 8) (Stocks-Fischer *et al.*, 1999). Alkaline pH is the primary means by which microbes promote calcite precipitation (Fujita *et al.*, 2000).

$$Ca^{2+} + Cell \rightarrow Cell\text{-}Ca^{2+} \quad (6)$$

$$Cl^- + HCO_3^- + NH_3 \leftrightarrow NH_4Cl + CO_3^{2-} \quad (7)$$

$$Cell\text{-}Ca^{2+} + CO_3^{2-} \rightarrow Cell\text{-}CaCO_3 \downarrow \quad (8)$$

Sand cementation through bacterial carbonate precipitation

The evidence of microbial involvement in carbonate precipitation has subsequently led to the exploration of this process in a variety of fields. Bio-cementation or Bio-Grout is a sand consolidation technology, in which ureolytic bacteria release carbonate from urea hydrolysis in the presence of an excess of calcium ions to form calcite ($CaCO_3$) in-situ. Under the proper conditions, this calcite can result in soil solidification and has found significant commercial interest (Al-Thawadi, 2008). In geotechnical engineering, the sandstone is produced by filling the sand voids with chemical grouts in a process called chemical cementation or chemical grouting. Chemical cementation depends on chemicals such as sodium silicate, calcium chloride, calcium hydroxide (lime), cement, acrylates, acrylamides and polyurethanes to bind the sand granules. Construction materials cemented chemically are subjected to weathering which leads to increase the porosity changing the mechanical features of the cemented materials (Tiano *et al.*, 1999). Bio-cementation could be greatly enhanced by using microorganisms with high urease enzyme activities indirectly involved in $CaCO_3$ consolidation (Stocks-Fischer *et al.*, 1999). Besides the high urease activity, a high tolerance to urea, calcium, ammonium and either nitrate or chloride (depending on the calcium salt used) enhance the bio-cementation (Whiffin *et al.*, 2007).

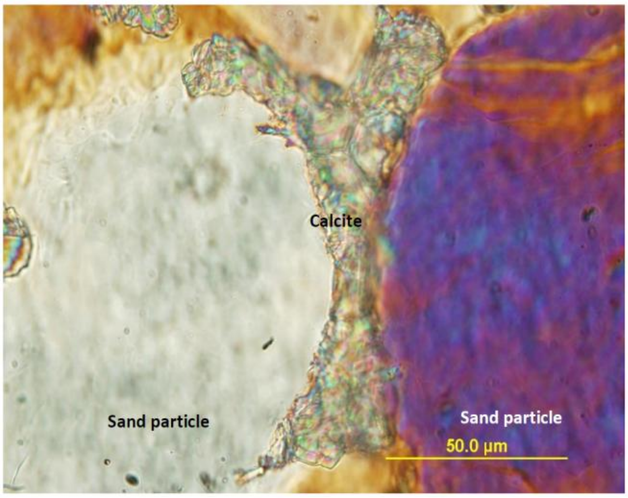

Fig. 1. Light microscopic image for calcite crystals produced by ureolytic bacteria binding two sand particles (Al-Thawadi, 2008)

Erosion control through sand cementation in Bangladesh

Heavy discharge currents through the GBM (Ganges-Brahmaputra-Meghna) river system, wave action due to strong southwest monsoon winds, high astronomical tides as well as sea level rise (SLR), and storm surges in the Bay of Bengal are the main causes of erosion in the coastal area of Bangladesh (Ali, 1999). Danjo *et al.* (2013) proposed a new method to protect coastlines from erosion – the use of artificial rock that auto-repairs by means of sunlight, seawater, and bacteria as microbially induced carbonate precipitation method. Their model of artificial rock is beachrock. Beachrock is a type of sedimentary deposit that generally occurs on tropical and subtropical beaches as a result of intertidal lithification of loose beach sands and gravels by carbonate cementation (Ginsburg, 1953). Calcium carbonate precipitation by ureolytic bacteria has attracted great attention recently. Several patents have been filed in bio-deposition (Europe), remediation of concrete (USA), bio-mineralization (China) and high strength production (Australia) (Al-Thawadi, 2011). In near future the field application of this technology, calcium carbonate precipitation, would be used for the erosion control for coastal areas in Bangladesh.

Conclusions

This bibliographical study has enabled us to gather information that should prove useful for sand cementation through microbial carbonate precipitation. In the future, it may possible to manufacture artificial rocks through sand cementation for erosion control purposes and it may also be possible in Bangladesh. Although bio-cementation technology is a promising technology due to its suitability to field application, it also results in an environmental problem due to its high production of high concentration of ammonium.

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