MICP Tactic for Expansive Soil of Vidarbha Realm

Atul D. Gautam[1], Arya R. Marjive[2], Nishant B. Bhele[3], Tanmay J. Raut[4], Rushikesh S. Sawarkar[5]

Department of civil engineering, JD college of engineering and management, Kalmeshwar Road, Phata, Nagpur, Maharashtra 441501

Abstract

Using urea hydrolysis, microbial-induced calcite precipitation (MICP) is a relatively new approach for granular soil improvement. The methodology used for infusing the reagents of ureolysis bacteria, urea, and calcium is crucial for acquiring uniform calcite deposition spanning the treated soil amount. This intricate procedure entails the enzymatic breakdown of urea by specialized bacteria housing the urease enzyme, all while submerged in a solution of dissolved calcium ions. The consequence is the remarkable precipitation of calcium carbonate. An innovative methodology has been devised to augment the anchoring and uniform dispersion of bacterial cells, along with optimizing their enzymatic activity within soil. This breakthrough aims to significantly enhance the viability of microbially induced carbonate precipitation as a ground reinforcement technique, particularly in expansive soil conditions.

Keywords: Hydrolysis, MICP, enzymatic, intricate, expansive soil.

1. Introduction

The mechanical attributes of soil, encompassing cohesion, friction, rigidity, and permeability, stand as pivotal determinants for both engineering construction and ecosystems within sedimentary settings. Conventionally, the soil's inherent characteristics are uniquely tailored to each locale, intricately woven into the fabric of current and past sedimentary effectual, as well as human interventions. There are two approaches in Microbial Geotechnology: bioclogging and biocementation (Ivanov and Chu, 2008)[1]. Bioclogging, an ingenious process, entails the creation of pore-filling materials via microbial activities, effectively diminishing the porosity of debilitated soil. Biocementation, on the other hand, mobilize the production of particle-binding materials in situ through microbial interactions, imparting enhanced shear strength to the soil. Exceptionally, these methodologies offer substantial potential for disaster mitigation and coastal management strategies. In compendium, bioclogging and biocementation may be regarded as specialized variants of soil improving techniques.

Chemical grouting of soil is a common technique in civil engineering (Karol, 2003)[2]. Irregardless, it's worth noting that chemical grouting may entail higher costs in comparison to the more ecologically alternative, bio grouting. Furthermore, many chemical grouts pose risks of toxicity to both humans and the environment. A notable advantage of biocement, when weighed against its traditional cement counterpart, lies in the magnificent property of low solution viscosity, which facilitates its permeation into porous soil under the influence of gravity. This characteristic makes biocement an environmentally friendly and cost-effective option in contradiction to conventional cement.

Drawing from their empirical investigation employing microscopy (DeJong, Fritzges, and Nusslein, 2006)[3] revealed a noteworthy observation. Their study indicated that calcium carbonate crystals did not manifest directly on the surface of soil particles but especially accrued in close proximity to the occasion points where soil particles made contact. This fascinating phenomenon can be attributed to the inherent biological attributes of micro-organisms, which exhibit a propensity to adhere to more confined surfaces. Consequently, the concentration of microbes is notably elevated in the environs of these narrow contact regions between soil particles, ultimately leading to an augment calcium carbonate precipitation.

In comparison to other natural disasters like earthquakes, floods, etc., expansive soils are responsible for a greater number of damages to structures, particularly light buildings and constructions. Consequently, these soils are regarded as problematic soils globally and provide engineers with a number of difficulties. So adequate soil treatment is necessary in order to effectively utilize these soils. An effort is undertaken to alter the engineering characteristics of black cotton soils from the Nagpur district of Maharashtra, India. The site's soil came from the Katol Road area of Nagpur. The outcomes of tests to ascertain the various characteristics of soil include. According to IS 2720 Part IV, the material's grain size distribution demonstrates that the majority of it, or 74.69%, is made up of tiny particles. Understanding the material's composition requires having this knowledge. The material's specific gravity (G), which is 2.65 according to IS 2720 Part III, is also supplied along with the grain size distribution. For many engineering and construction applications, specific gravity is a crucial quantity that sheds light on the material's density. Additionally, based on IS 2720 Part II specifications, the material's natural water content (w) is found to be 9.29%. Assessing a soil's appropriateness for building and identifying its technical qualities depend heavily on its water content[4].

These findings are vital for characterizing the particle size distribution of the sample and contribute valuable insights for various applications, such as geotechnical and material engineering, where understanding the granulometric composition of materials is of paramount importance.

2. Microbial induced calcite precipitation (MICP)

2.1 Introduction

Currently, the global construction sector is expanding quickly in tandem with national growth. More cement products are required in order to satisfy all construction-related demands. Cement manufacture alone takes a significant quantity of fuel as an energy source (Pacheco-torgal et al., 2016)[5].

Sporosarcina pasteurii, a bacterium that generates the urease enzyme that hydrolyzes urea to cause the precipitation of CaCO3, is a biological technique that has been utilized to enhance or strengthen the qualities of many types of soils or sands (Arab, 2019)[6]. In soil particles, strong bonding interactions are enhanced by the precipitation of CaCO3 (Nafisi et al., 2018)[7].

The microorganism is active in the presence of water and is capable of developing in both aerobic and anaerobic environments (Rahman et al., 2015)[8]. It uses many nutrients as a source of energy to thrive, including nutrient broth, carbon, nitrogen, and others (Seifan and Berenjian, 2018)[9]. It significantly contributes to environmental preservation (Rahman et al., 2015)[8] and sustainably strengthens soil. It is a more advantageous approach due to its low cost, range of applications, independence from climatic conditions, and simplicity of use (Peng and Liu, 2019)[10].

Although all bacteria are photosynthetic organisms which can precipitate CaCO3 in the presence of urea and calcium ions, Sporosarcina pasteurii bacteria are preferred because they are non-toxic to people (Siddique and Chahal, 2011)[11].

2.2. Literature review

Utilizing ureolytic bacteria in submerged fermentation, it is feasible to develop soil-stabilizing bio enzymes. Additionally, it was shown that bio enzyme treatment of expansive soils can enhance the subgrade quality for use as material for the base course or sub-base of a road. However, it was also found that these gains were insufficient to render the soil suitable for these uses (Mekonnen et al., 2022)[12].

(Barman & Dash, 2022)[13] Buhler and Cerato (2007) pointed out that if inflation and population growth are taken into account, the expansive soil induced annual losses in the USA might exceed $15billion.Jones and Holtz (1973) stated that, in a particular year, the shrink-swell damage might exceed the combined annual losses from other natural hazards such as earthquake, flood, tornadoes and hurricanes.

(Rajasekar et al., 2021)[14] In order to check the viability of the method for potential field conditions, the tests were carried out at slightly less favourable environmental conditions, i.e., at temperatures between 15-17℃ and without the addition of urease enzymes. Furthermore, the sand was loose without any compaction to imitate real ground conditions. The results showed that the indigenous bacteria yielded similar permeability reduction (4.79E-05to5.65E-05) and calcium carbonate formation (14.4–14.7%) to the control bacteria (Bacillus megaterium), which had permeability reduction of 4.56E-5 and $CaCO_3$ of 13.6%. Also, reasonably good unconfined compressive strengths (160–258kPa) were noted for the indigenous bacteria samples (160kPa).

(Soundara et al., 2020)[15] By using Microbial induced calcite precipitation (MICP) process. This process of MICP is carried out by adding bacterial solution into soil specimen which is continued with inoculation of cementation reagents having urea and one calcium salt ($CaCl_2$) for enormous times. As a result, calcite precipitate ($CaCO_3$) is formed in the soil and stabilize the soil. In bio-clogging process the soil void spaces are reduced by bio-cements which are generated by bacterial calcium carbonate precipitation processes. Concentration of cementing solutions $CaCl_2$-urea in the range of 0.3 M to 0.7 M gives higher unconfined compressive strength. Beyond 0.7 M of cementing solution concentration reduces the UC strength of soil. Eggshell cementing solution is more effective in MICP technology than calcium chloride cementing solution.

(Li et al., 2018)[16] Expansive soils are present throughout the world that have tendency to swell upon increase in moisture content. There is extensive damage caused by soil expansion reported from many countries worldwide. Such soils impose a potential risk to safety of civil engineering structures including highways, bridges, railways, airports, and seaports constructed on expansive soils. When behaviour of soils changes, it promotes severe land degradation. Thus, it is very important to stabilize expansive soils. Soil stabilization is the most common ground improvement technique that modifies soils to improve the engineering properties including strength of soils.

(Omoregie et al., 2017)[17] MICP is highly desirable because of its natural availability, effectiveness and sustainability. The sand columns were injected with S. pasteurii (NCIM 2477) and cementation solution under gravimetric free flow direction for the duration of 120 h. Their finding showed that the $CaCO_3$ contents precipitated in the sand columns were mostly deposited at the upper layer (40%) which led the reduction of soil porosity and permeability.

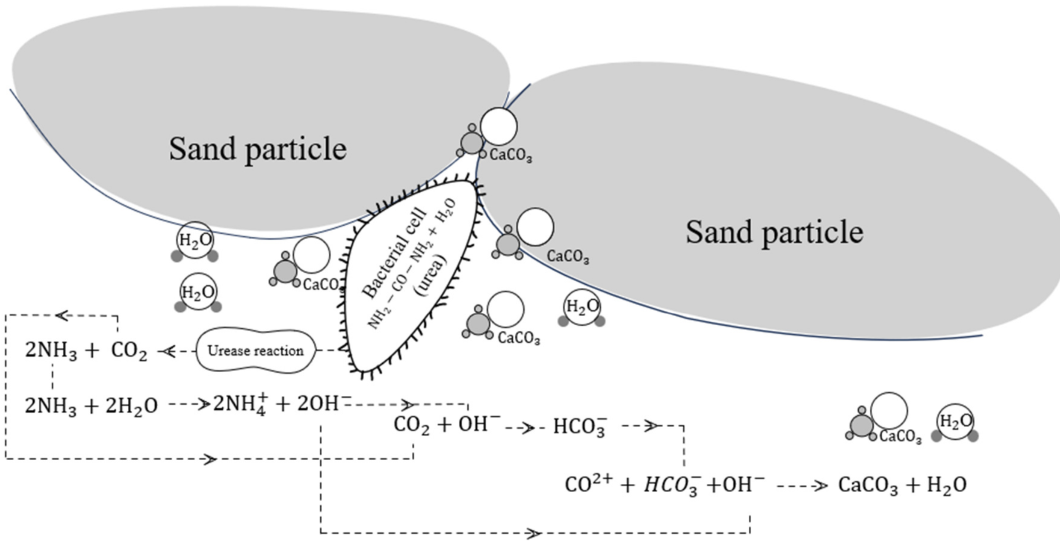

Fig no.1 The MICP process by urease producing bacteria in the presence of urea and calcium.

The bacteria produce urease, which causes the urea to hydrolyze and decompose into ammonia (NH_3) and carbon dioxide (CO_2). The pH in the region rises when ammonia (NH_3) dissolves in water to produce ammonium ions ($NH_4{}^{+}$) and hydroxide ions (OH^-). When carbon dioxide (CO_2) dissolves in water, bicarbonate ions (HCO_3^-) and hydrogen ions (H^+) are created. This bicarbonate (HCO_3^-) reacts with the hydroxyl ions (OH) in a high pH environment to produce carbonate ions (CO^{2+}). Calcium carbonate ($CaCO_3$) is created by calcium ions ($Ca_2{}^{+}$), which precipitates out quickly because it has a low solubility in water.

3. Control parameters of microbially induced calcite precipitation

Several parameters should be managed during the process, including bacteria, soil, cementation solution, pH, temperature, and injection system, for the efficient and effective way of manufacturing CaCO3 precipitation, which is a fundamental cementing material (Terzis and Laloui, 2019)[18].

3.1. Bacteria parameters

In general, bacteria are utilized to speed up the decomposition of urea into carbon dioxide and ammonia as well as serve as a nucleation site for Ca2+ accumulation in their cells because of their highly negative charge. The increasing pH values inside the solution are what have caused this negative charge. Sporosarcina pasteurii/Bacillus pasteurii is the best kind of microorganism due to its high urease activity, capacity to thrive at pH levels over 8.5, and comparatively strong resistance to the ammonia impact (Ivanov and Stabnikov, 2017)[19].

All of the microorganisms are between 0.5 and 3.0 mm in size. However, Sporosarcina pasteurii, the most common bacterium, has a size of 1 mm (Kadhim and Zheng, 2016)[20]. The environment is unaffected by these microorganisms (Haouzi and Courcelles, 2018)[21].

3.2. Soil condition

The soil pores should be sufficient in size to allow bacteria to move around freely. The size should be between 50 and 400 mm since it has a significant impact on MICP (Kadhim and Zheng, 2016)[20]. The amount of CaCO3 that is precipitated or deposited varies depending on what type of soil. This variation is brought about by the sand or soil's behaviors with regard to temperature, size (small-particle sands/soils are preferred, and for coarse particles, more precipitated CaCO3 must be employed to have the desired strength), and particle shape (spherical/ellipsoidal particle morphology is required) (Inagaki et al., 2011)[22].

3.3. Cementation solution

The quantity of CaCO3 precipitation is significantly influenced by the chemical solutions produced. A greater UreaCaCl2 solution concentration facilitates in the MICP process' efficiency. More calcite precipitates in every void or gap as a result of the cementation solution's excellent preparation, which surrounds the particles and increases their overall strength. According to some researches, cementation medium concentrations between 0.25 and 0.5 M provide adequate precipitation, but anything more than this would not be completely used and would have less of an impact on the amount of CaCO3 that precipitates and the strength of the material.

3.4. pH

It is more efficient to precipitate CaCO3 using the MICP method in an alkaline or weakly basic environment. In acidic environments or at pH levels less than 7, some bacteria may create CaCO3, but they are not preferred since they are dangerous to people. The optimal pH for the urease enzyme has been shown to be 8 in several investigations (Soon et al., 2014)[23]. The production of ammonium ion (NH_4^+) from urea hydrolysis in the presence of Sporosarcina pasteurii bacteria is what causes the solution's pH to rise.

3.5. Temperature

One fundamental component that might have an impact on the entire process and the effectiveness of the generated CaCO3 in any application is temperature. The variance in crystal size of the precipitated calcium carbonate is what prevented the generated CaCO3 from having the same strength in the same amount of chemical solution, period of time, and pH but at different temperatures. As a consequence, having more precipitated CaCO3 does not always indicate that a system is strong (Kim et al., 2018)[24]. There was no response when the temperature was below 5oC, contrary to what many researchers observed, and the ideal temperature range for the efficient and maximal precipitation of the CaCO3 ranged between 20oC and 37oC (Kadhim and Zheng, 2016)[25].

3.6. Injection strategies

The cementation solution can be injected into the designated soil type in a number of different methods. The volume and effectiveness of calcite precipitation are influenced by the injection method. The inappropriate mixing or injection of the bacteria solution, as well as the accumulation of the bacteria in one location, are the causes of the non-uniform distribution of CaCO3 throughout the sample.

4. Future scope

The solution to this issue is to introduce smaller-sized bacteria that are dead but still active in their ureolysis activity. As MICP research develops, it has the potential to completely transform a number of industries by offering environmentally benign, economically viable resolution to a range of soil-related problems. Unlocking the full potential of this technique will need cooperation between microbiologists, geotechnical engineers, environmental scientists, and material scientists. Only soils and sands with a particle size of less than one micrometer are suitable for the chosen Sporosarcina pasteurii bacteria. The use of MICP to soil remediation may be expanded to address a number of pollution-related problems, such as acidic soils and heavy metal contamination. It is also helpful in containing and immobilizing pollutants locally.

5. Conclusion

The MICP method represents a natural and biological approach to generating eco-friendly construction materials, specifically bio-cement, at minimum temperatures and costs, all while maintaining an environmentally conscious stance with no greenhouse gas emissions. The efficacy of this bio-cement hinges significantly on achieving a homogeneous dispersion of the resulting $CaCO_3$ within the target sample of soil.

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