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Bio-Modification of Geomaterials Through MICP

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Abstract: To meet the needs of growing infrastructure development, the existing poor soils must be improved in order to enable the facilities to be constructed. This is achieved through an emerging improvement technique Microbial Geo-technology using the process of Microbial Induced Calcite Precipitation (MICP). In the present study, Sporosarcina Pasteurii bacteria was used for the precipitation of calcite mineral to bind the soil minerals. Bacterial cell solution was injected into the soil specimen through single staged injection. The soil specimens were treated using a standard concentration bacterial cell and with varying urea-calcium chloride solutions. Liquid incubation medium which is containing Ammonium Chloride (NH4Cl) was used to test the growth of bacteria. The treated samples shown good strength performance from Unconfined Compressive Strength (UCS) tests. The permeability coefficient values showed a reduction by a magnitude of one order

Index Terms-MICP, Permeability, Urea Hydrolysis and UCS

1. INTRODUCTION

Continued rehabilitation and the expansion of civil engineering infrastructure requires us to meet the construction demands by modifying the existing poor soils since it is not possible to get competent soil conditions at our site. Conventional ground improvement techniques includes the densification of soil or dewatering or reinforcement etc. among which the densification is most commonly used. The densification can be achieved by using mechanical energy or by grouting a binding agent like cement, epoxy resins or silicates etc. (Karol, 2003). Even though they are quite effective, they include high costs and may possess environmental issues besides requiring availability and constructability. According to NRC (2006), Geotechnical engineers need a new understanding of geomechanics to reduce the potential damage to the environment. Hence an interdisciplinary research, especially, the interaction between biotechnology and geotechnical engineering, explores the use of biological methods to solve the geomechanical problems.

The current study examines the effects of bio-stabilization through Microbial Induced Calcite Precipitation (MICP) process on the engineering properties of geomaterials. MICP has gained much attention recently due to its versatile applications from geotechnical engineers and researchers all-over the world. MICP can be achieved through many biological processes. Among these, MICP through the hydrolysis of Urea using ureolytic bacteria has been used mostly and was adopted in this study. Usually, the urea hydrolysis is a slow reaction which becomes faster in the presence of urease enzyme. The Sporosarcina Pasteurii, formerly known as Bacillus Pasteurii, was introduced in soil specimens to release urease enzyme in order to enable urea hydrolysis. The process of MICP was shown in figure 1 and was explained in equations 1 and 2.

$$CO(NH_2)_2 + 2H_2O \rightarrow 2NH_4^{+} + CO_3^{2-} \qquad Eq(1)$$
$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3(\text{precipitate}) \qquad Eq(2)$$

During the process of MICP, the urea is hydrolyzed to ammonium and carbonate ions in the presence of urease enzyme. The carbonate ions in the presence of calcium ions forms the calcite minerals which binds the soil particles enabling the bio-stabilization.

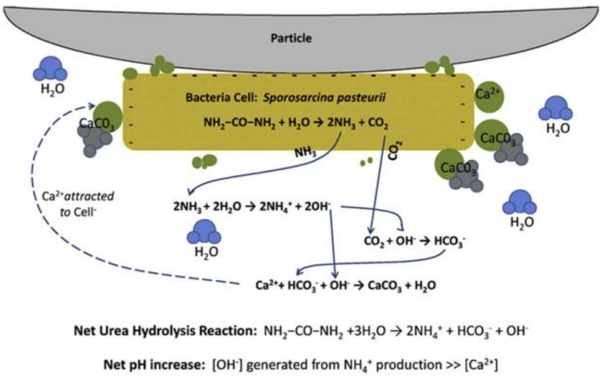

Figure 1. MICP process by Urea Hydrolysis (Reproduced from DeJong et al. 2010)

The utilization of biological process in modification of engineering properties of geo-materials had emerged in the recent years (DeJong et al., 2006). This method is environmental friendly and sustainable ground improvement technique. According to Ramakrishnan et al. (2005), all the additives used in this method are environmental friendly. Bio-stabilization and Bio-clogging are two important terms of Bio-modification depending upon the application. Bio-stabilization binds the soil solids through the biologically produced precipitates; thus increasing the strength whereas, Bio-clogging plugs the pores of particles through those precipitates within the target areas by immobilizing the urease active bacteria; thus reducing the permeability. According to DeJong et al. (2010), improvement of strength and stiffness of MICP treated soil will be influenced by the densification and bonding effects of the mineral precipitation. DeJong et al. (2006) suggested Bacillus Pasteurii (presently known as Sporosarcina Pasteurii) as a stabilization microorganism applicable in soil modification. The pore size of soil should be sufficient for allowing movementbacteria 0.5-3.0µm in length (Mitchell and Santamarina, 2005). Rebata-Landa (2007), reported that the most favourable particle size of soil will range from 50-400µm for bacterial activity. In the current study, Sporosarcina Pasteurii, an aerobic, gram positive bacteria and having level one bio-safety rating was used to treat the sand specimens

2. MATERIALS

2.1 Bacterial Cell Solution

Sporosarcina Pasteurii which occurs naturally in soil was used in the study by procuring them in freeze-dried vial from the Microbial Type Culture Collection (MTCC) instead of culturing from soil. Agar medium was used to provide nutrients to grow the bacteria and later the liquid medium including four reagents to culture the bacteria. After the complete culturing of the bacteria, the bacterial cells were re-suspended at desired concentrations in nutrient broth (NB) – urea soluti on which comprises 3g of NB, 20g of urea, 10g of ammonium chloride and 2.12g of sodium bicarbonate per litre of deionized water.pH value of this solution was adjusted to 8.5 using 4M HCl solution prior to autoclaving.

2.2 Cementitious solutions

Different combinations of urea and $CaCl_2$ concentrations were investigated. The combinations were shown in table 2

2.3 Sand

In the current study, the sand samples were collected from the surrounding places of NIT Warangal, Telangana, India. The index properties of the sand samples found according to IS 2720 were presented in table 1 and the grain size distribution curve was shown in figure 2

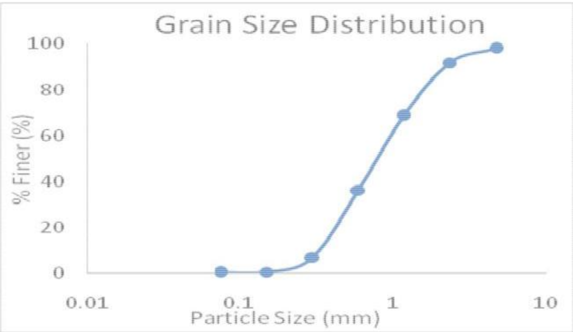

Figure 2. Grain Size Distribution Curve

Table 1. Index Properties of Sand

Soil	G	C_u	C_c	I_D	*Soil type*
Sand	2.66	4.39	1.86	35	SP

3. METHODOLOGY

3.1 Sample Preparation

The UCS split moulds were used for the preparation of samples as per Ismail (2000). A rubber membrane was placed in contact with inner wall of each mould. At the bottom of each mould a porous stone was placed. 150g of dry sand air was poured slowly into each of the specimen in three layers of approximately equal thickness. Each layer was gently compacted individually by tapping the outer wall of the mould such that the specimen produced will be in a loose state (Relative density = 35%).

3.2 Injection Strategy

For the successful treatment, it is required to inject the bacterial cell and cementitious solutions uniformly followed by bacteria permeation throughout the specimen along with bacterial cell fixation. In the present study, single staged injection (downward flow) was followed. Firstly the samples were de-aired by permeation of water. Now the bacterial cell solution was injected into the specimen which is retained for 24 hours under a pressure head applied during injection. Using a peristaltic pump, required amount of medium, $CaCl_2$ and urea were allowed to flow. After 24h retention period, each specimen was allowed to drain under gravity

3.3 Lab Tests

The treated specimens were allowed for treatment by bacteria for 21 days. To understand the effect of bio-stabilization, the UCS tests were conducted on the treated sand specimens according to IS 2720. Constant head permeability test was used to identify the change in permeability of sample and is compared with the permeability of untreated sample. Besides these tests, X-ray Diffraction (XRD) analysis was carried out to check the effect of MICP.

4. RESULTS AND DISCUSSIONS

4.1 XRD

The constituents of the MICP were examined using XRD tests. The XRD analysis of untreated and treated sand specimens were shown in figures 3 and 4 respectively. From figure 3, the main constituent of untreated sand was quartz whereas the constituents aragonite, dolomite and olivine (different phases of $CaCO_3$) observed in figure 4 were from bio-stabilization

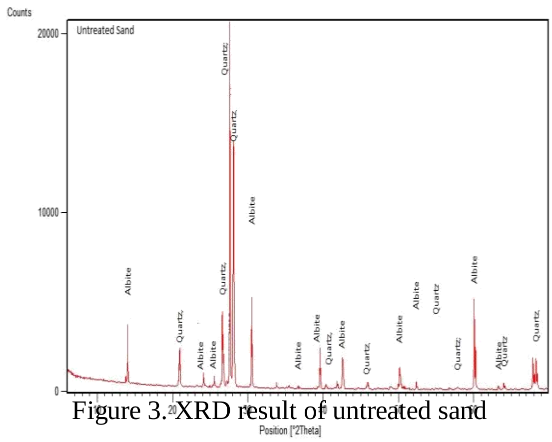

Figure 3. XRD result of untreated sand

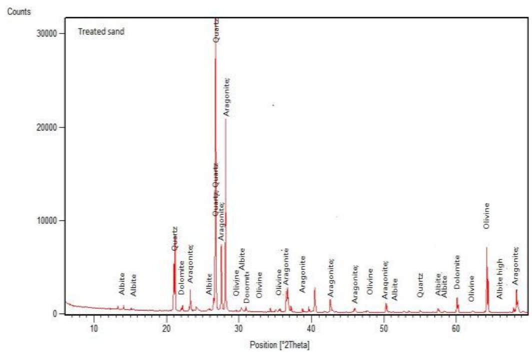

Figure 4.XRD result of treated sand

4.2 UCS

The effects of bacterial treatment was assessed by comparing UCS values. At same bacterial cell concentration (1 x 10^8 cells/ml), treated specimens showed higher UCS values with higher urea-$CaCl_2$ solution concentrations as shown in table 2. Similar results were reported by Yasuhara et al. (2011). The lowest and highest UCS values were observed to be 56kPa and 296kPa mobilized for the solution concentrations of 0.1M urea-0.1M $CaCl_2$ and 1.85M urea-1.0M $CaCl_2$ respectively which are in line with those reported by Whiffin et al. (2007) and Palme'n (2012).

The stiffness values were observed to be increased with the MICP treatment as shown in figure 5.

4.3 Permeability

The permeability values were presented in table 2 for all the treated and untreated specimens. Approximately similar results of permeability were reported by previous MICP studies on sand (Soon et al., 2013, Whiffin et al., 2007 and Yasuhara et al., 2011). Compared with untreated sample, the treated specimens showed a minimum reduction of 50% permeability and maximum value of 94%. A reduction of one order magnitude was observed

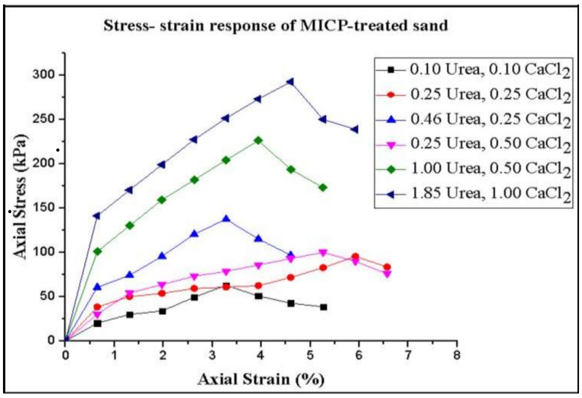

Table 2. UCS and Permeability Values for different concentrations of Urea-$CaCl_2$

Cementation Combination	Urea (M)	$CaCl_2$ (M)	UCS	Permeability coefficient (m/s)
Untreated	0	0	-	4.64 x 10^{-4}
1	0.10	0.10	56	2.33 x10^{-4}
2	0.25	0.25	95	1.69 x10^{-4}
3	0.46	0.25	138	1.41 x10^{-4}
4	0.25	0.50	100	1.62 x10^{-4}
5	1	0.50	226	8.28 x10^{-5}
6	1.85	1	296	2.61 x10^{-5}

5. CONCLUSIONS

Based on the experimental findings of the current study, the following conclusions were drawn:

- Single-staged injection was significant for bio-stabilization.
- MICP through urea hydrolysis significantly increased the average UCS of the sand.
- Coefficient of permeability values were found to be reduced by approximately one order magnitude for MICP treated specimens.
- There seems to be a great promise in using bio-treatment in ground modification.

6. SCOPE FOR FUTURE WORK

The experiments involving biological processes for soil modification have been largely confined to the laboratory studies. More research is required to develop full scale applications. Research need to be carried out to find whether the microorganism is still alive after application and develop in-situ living conditions. Trails could be made on other kinds of soils instead of sand

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