Effect Of Microbial Induced Calcite Precipitation (MICP) On Strength Of Soil

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Abstract. The challenges to Improve the weak soil consistently produce the need for research and investigation to develop a new, advanced, eco-friendly and sustainable method of soil stabilization. One possible technique is Microbial-Induced Calcite Precipitation (MICP) which has recently developed and emerged as a sustainable technique for soil improvement. This study focuses on calcium carbonate precipitation through bacterial population and its effect on the strength and compressibility of soil. Two different types of soils (high plastic clay and low plastic clay) were used for the study. A species or strain of Bacillus group Bacillus megaterium (MTCC-428) was used to activate and catalyze the calcite precipitation caused by chemical reaction between calcium chloride and urea. MICP uses bacteria to hydrolyses urea and give carbonate ions which react with a calcium chloride solution which produce calcium carbonate (calcite) that binds and hold the soil particles together which leads to improve strength of soil and increase stiffness. A special nutrient delivery system was use to induce cementation reagents. Variable parameters such as concentration of cementation reagent (0.25M, 0.50M, 0.75M, 1M) and curing period (1day, 3day, 7day) were studied. These parameters were applied on both the type of soils in specified duration and range to utilize the effect of MICP. From the results there were perceived improvement (1.15-2 times) in unconfined compressive strength in both the type of soils. It was also found that the strength increased with increment in treatment duration. The results from Scanning Electron Microscope (SEM) analysis validate the experimental results.

Keywords: Soil stabilization; Calcite precipitation; B.megaterium; Unconfined compressive strength.

1 Introduction

The need for stabilizing soils becomes necessary mainly because of weak or poor soil properties and need for urbanization especially in areas with problematic soils. It is believed that the demand for new and sustainable soil stabilization techniques is increasing rapidly. The artificial cementation of soil particles due to soil stabilization is often achieved through the use of chemical stabilizers via shallow and deep mixing or injecting chemical grouts that can permeate through soils. Physical properties of

soil can be modified by the use of mechanical compaction or compaction grouting while chemical properties of soil can be modified by the use of chemical stabilizers such as Portland cement, lime and fly ash. Mechanical compaction is recommended for sandy soils and is effective or economical to a depth less than 10 m (Ivanonv & Chu, 2008). Chemical stabilization is typically recommended for expansive soils (Petry & Little, 2002). Environmentally safe techniques such as pre-wetting and moisture barriers are only possible for small confined spaces, and are not suitable for larger construction projects such as highways and railways which spread for miles. Traditional ground improvement techniques have many limitations. High pressures are required to inject the grouts due to their fast hardening time or high viscosity. Freezing is not a permanent solution during construction. Most of these methods are expensive, disturbing urban infrastructure, require heavy machinery, and involve chemicals with significant environmental impact. Consequently, these conventional methods are not suitable for treating large volumes of soil. Artificial cementation techniques are never feasible and environment friendly. However, decrease in the use of artificial cementation techniques can be done by addition of environmental friendly methods or materials.

One such method of soil stabilization technique is, Microbial Induced Calcite Precipitation (MICP). MICP technique is a better and more environmentally friendly alternative to the conventional technologies. This technique employs microbes as a primary factor for stabilization. Calcium carbonate precipitation has been induced inside the soil structure by microorganism through their metabolic process to improve the engineering properties of soil. Hence, this technique is called as microbial induced carbonate precipitation or MICP. Successful implementation of MICP will have its application in a wide variety of civil engineering fields such as stability of retaining walls, embankments and dams, controlling soil erosion, stabilizing cohesion less soils to facilitate the stability of underground constructions, increasing bearing capacity of shallow and piled foundation and reducing the liquefaction potential of soil.

2 Theoretical Background

Lee Min Lee et al. (2012) studied the effect of MICP (Lee Min Lee et al., 2012) on shear strength and reducing hydraulic conductivity of soils. The results showed that MICP could effectively increase the shear strength and reduce hydraulic conductivity of soils. In general, MICP can be achieved by urea hydrolysis, aerobic oxidation, de-nitrification, sulphate reduction, etc. Urea hydrolysis refers to a chemical reaction where urea ($CO(NH_2)_2$) is decomposed by Urease enzyme that can be either supplied externally (Greene et al., 2003), or produced in situ by Urease producing microorganisms (DeJong et al., 2006). Van Paassen et al. (2010) suggested that urea hydrolysis pos-sesses the highest calcite conversion rate compared to other studied

processes (Harkes et al., 2010; Whiffin et al., 2007). The latter process requires Urease positive type bacteria, i.e. genera Bacillus, Sporosarcina.

1 mole of urea decomposes into 2 moles of ammonium according to following reaction:

$$CO(NH_2)_2 + 2H_2O \rightarrow 2NH^{4+} + CO_3^{2-} \quad \_\_\_\_\_ (1)$$

The release of ammonium (NH4+) cause increase in pH, which in due course, creates a perfect circumstance for calcite precipitation with the availability of calcium ion(Ca^{2+}) from the supplied calcium chloride:

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3 \quad \_\_\_\_\_ (2)$$

The $CaCO_3$ precipitates formed are gelatinous in nature and thus helps in bonding the soil particles together.

3 Material and Methodology

3.1 Soil Characteristics

Two types of soils were considered for this study. Both soil samples were collected from Dholera (Gujarat, India).The basic properties of the collected samples and soil classification are in Table 1. These samples were treated with bacteria and cementation reagent and then tested for strength increment.

The Properties of materials that are obtained from the laboratory tests are:

Table 1. Properties of soil

Sr no.	Test	Symbol	Result Soil 1	Result Soil 2	IS Code
1	Liquid Limit	LL	54%	35%	IS 2720(Part 5)-1985
2	Plastic Limit	PL	26.57%	26.19%	IS 2720(Part 5)-1985
3	Plasticity Index	PI	27.43%	8.81%	IS 2720(Part 5)-1985
4	Soil Classification	-	CH	CL	IS 1498-1970

5	Shrinkage Limit	SL	22.59%	10.76%	IS 2720(Part 6)-1978
6	Specific Gravity	G	2.71	2.64	IS 2720(Part 3)-1980
7	Free Swell Index	FSI	14.5%	10.5%	IS 2720(Part 40)-1977
8	Hydrometer	Clay Silt	40% 56%	17% 61%	IS 2720(Part 4)-1985
9	Standard Proctor Test	OMC MDD	23.0 % 15.9 kN/m^3	19.0% 17.3 kN/m^3	IS 2720(Part 7)-1980
10	P^H	_	8.83	8.54	IS 2720(Part 26)-1987
11	Coefficient of permeability	K_h	1.03 x 10^{-9} m/sec	0.82 x 10^{-9} m/sec	IS 2720(Part 17)-1986

3.2 Activation and Cultivation of Bacteria

Bacterial strain bacillus megaterium (MTCC-426) is used for this research was ordered from microbial type culture collection and gene bank (MTCC) Chandigarh in freeze dried condition. freeze dried culture was taken in a petri plate which was previously solidified with agar. Which is incubated at -4°c temperature and under condition recommended for the culture. The growth media used to grow the microorganisms was primarily nutrient broth (NB).

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(a) (b) (c)

Fig.1. (a) Freeze dried culture (b) & (c) Activated culture on Petri plate

Microbial concentration tests were used in this research to determine the effect of microbial concentration in evaluating the effect of MICP in soils. In order to maintain the consistency of microbial concentration throughout the research, colony formation unit (CFU) method was adopted to determine the concentration of microbes in a given solution. After 48 hours of incubation, the optical density (OD) of these cultured microbes was measured. OD is the method of determining concentration of microbes in a sample by measuring the turbidity of the sample at certain wavelength, usually 600 nm. These cultured microbes were then serially diluted and After serial dilution, 10ml of the serial diluted media was taken and then plated in a NB plate. (NB plate was prepared by mixing 10 g of LB and 6 g of agar in 400 ml of distilled water. The media after autoclaving was poured into the petri dish. The media solidifies after few hours due to the presence of agar.) after 48 hours of plating, the number of colonies were counted. The CFU/ml for each serial dilution is given as per Equation.

$$\text{CFU/ml} = \frac{\text{No.of colonies counted} \times \text{Dilution factor}}{\text{Volume of culture}}$$

3.3 Cementation reagent

Cementation reagent serves as important ingredients for promoting calcite precipitation. As shown in equations (1) and (2), the ammonium (NH^{4+}) and calcium (Ca^{2+}) ions are decomposed from urea ($CO(NH_2)_2$) and calcium chloride ($CaCl_2$), respectively. It is thus important to supply sufficient amount of urea and calcium chloride into the soil. The cementation reagent also contained 3 gm nutrient broth, 10 gm NH_4Cl, and 2.12 gm $NaHCO_3$ per liter of water.

3.4 Laboratory Setup

Fig. 2 shows the schematic diagram of the laboratory setup. The test is carried out in a prefabricated mould, which has the provision of inlet and outlet and control of flow. The apparatus is of a split type acrylic mould of 90 mm internal diameter (ID) and 160 mm height. The setup consists of a reagent tank, prefabricated mould, inlet and outlet valve, and an effluent collector. Air compressor is used to apply the pressure in reagent tank to initiated the flow through soil specimen.

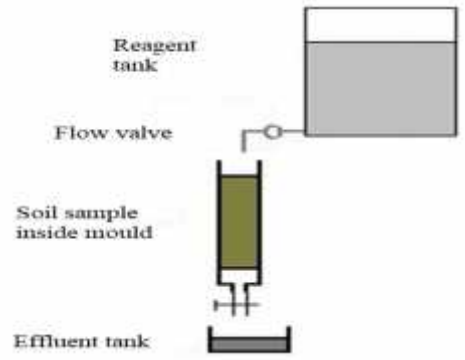


Fig.2. Schematic Diagram of Laboratory Setup

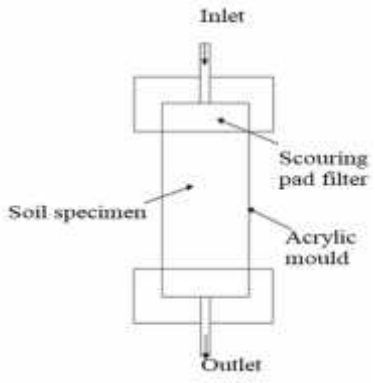


Fig.3. Soil Specimen Mould

3.5 Preparation of soil specimen

Initially, bacteria was added to the soil and mixed properly. Soil was compacted at 95% of MDD and respective OMC prior to treatment in the prefabricated mould. Since treatment duration was a parameter, soil samples of given molar concentrations were allowed for curing duration of 1, 3 and 7 days. For everyday treatment, 1litre of nutrients are allowed to pass through the sample. Upon the completion of the treatment, the soil was extruded from the acrylic mould and tested for its shear strength through the unconfined compression test.

3.6 Experimental Variables

Two different types of soils were used for these study .The main variable in this study was the concentration of cementation reagent and curing period. Four concentrations were adopted, i.e. 0.25 M, 0.5 M, 0.75M, and 1 M. Three parameters were selected for curing period, i.e. 1 day, 3day and 7 day.

4 Results and Discussion

4.1 Unconfined compressive strength

The stress strain curves of all the soil specimens tested in the unconfined compression testing machine. The UCS value for virgin soil sample 1 (CH Soil) was 178.63 kPa, which on treatment with MICP was found to increase further. The test results of soil sample 1 (CH Soil) are tabulated in Table 2. It was observed from the test results that by increasing the treatment duration, UCS values was increased. For soil sample 1 (CH Soil), highest increment was observed for molar concentration of 0.5 M of cementation reagent. UCS value further increased on increasing the treatment duration. The test results of soil sample 2 (CL Soil) are tabulated in Table 3. The optimum strength achieved at 0.5M concentration and the stress strain curves for that optimum value are shown in figure 4 and figure 5. For 0.50M, it shows highest increment in both CH and CL type of soil compared to other molar concentration because at 0.50M concentration gives the best favorable condition for bacteria to perform and produce maximum amount of urease enzyme for calcite precipitation. Higher bond formation in soil then lead to increase in cohesion of soil which is one of the parameters for the soil's shear strength and hence increase in soil strength.

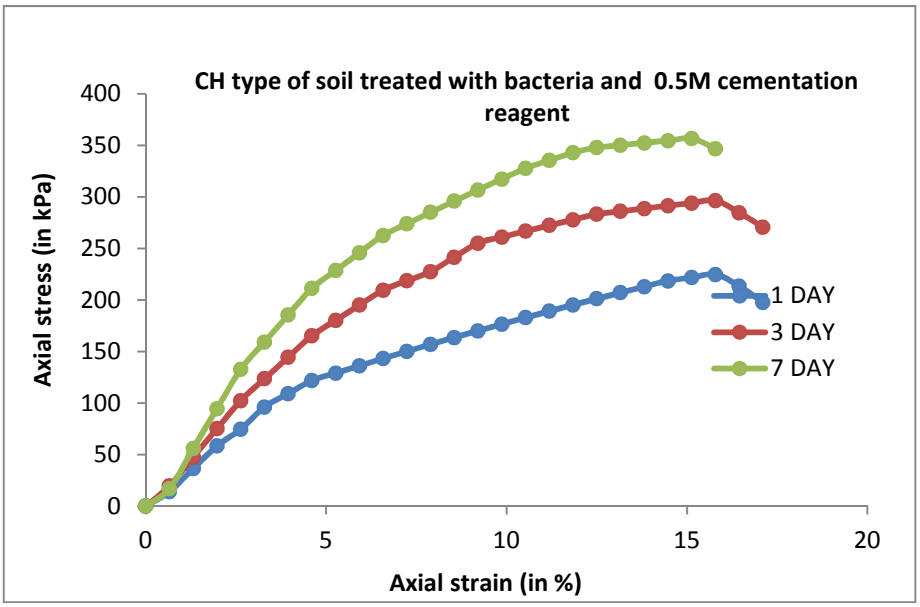


Fig.4. Stress-Strain curve for 0.5M cementation reagent (soil 1 – CH soil)

Table 2. Strength of Soil 1 (CH) soil after treatment

		Soil 1 (CH) Unconfined Compressive Strength (kPa)			
Bacteria	Cementation reagents	Untreated	1 day	3 day	7 day
Bacillus Megaterium 1×10^{8} CFU/ml	0.25 M	178.63	205.66 (1.15 times)	255.47 (1.43 times)	279.59 (1.56 times)
	0.50 M	178.63	224.79 (1.25 times)	296.54 (1.66 times)	356.70 (1.99 times)
	0.75 M	178.63	211.31 (1.18 times)	260.67 (1.46 times)	308.50 (1.25 times)
	1.0 M	178.63	199.16 (1.11 times)	225.88 (1.26 times)	301.78 (1.69 times)

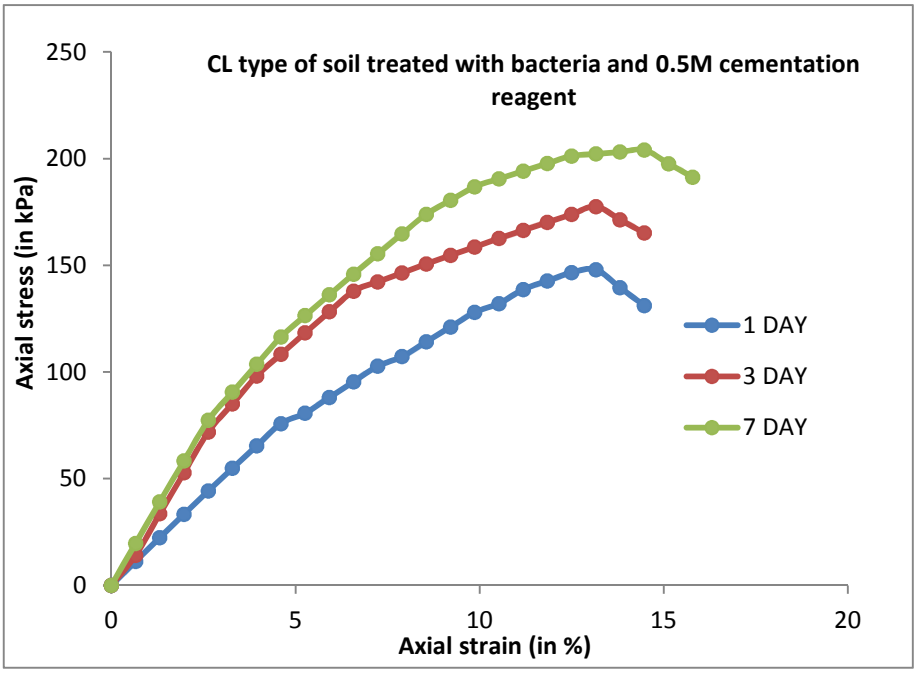
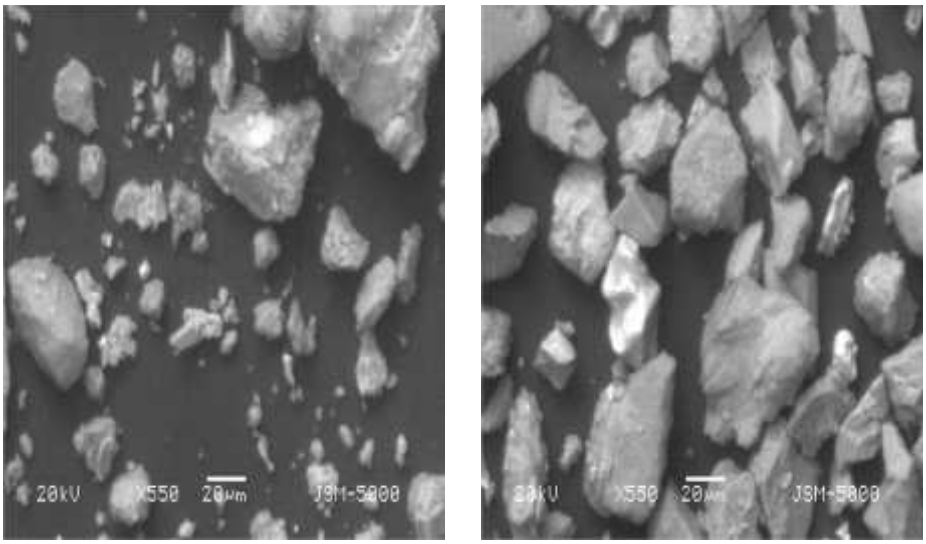


Fig.5. Stress-Strain curve for 0.5M cementation reagent (soil 2 – CL soil)

Table 3. Strength of Soil 2 (CL) soil after treatment

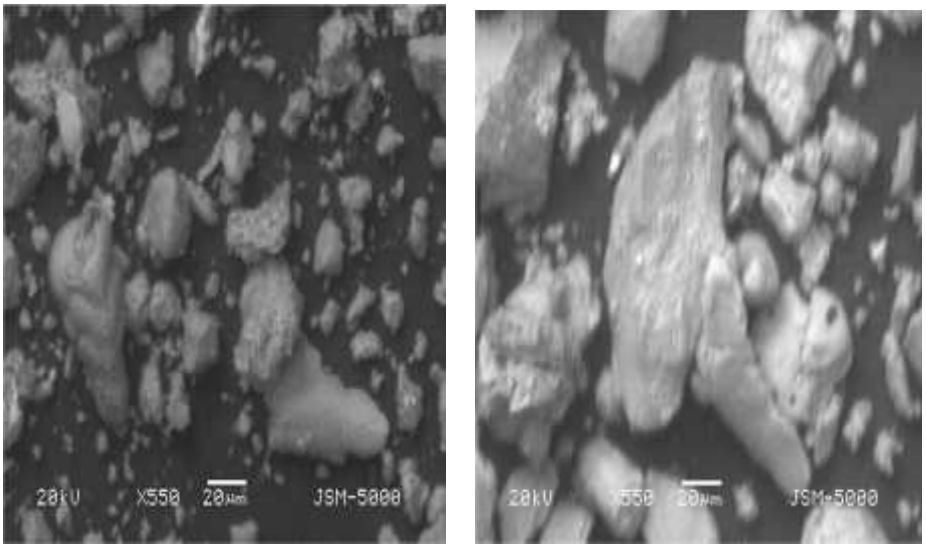
		Soil 2 (CL) Unconfined Compressive Strength (kPa)			
Bacteria	Cementation reagents	Untreated	1 day	3 day	7 day
Bacillus Megaterium 1×10^8 CFU/ml	0.25 M	104.05	128.24 (1.23 times)	141.96 (1.36 times)	184.59 (1.77 times)
	0.50 M	104.05	147.97 (1.42 times)	177.57 (1.71 times)	204.02 (1.96 times)
	0.75 M	104.05	138.11 (1.33 times)	167.70 (1.61 times)	194.83 (1.87 times)
	1.0 M	104.05	123.3 (1.19 times)	151.75 (1.46 times)	186.01 (1.78 times)

4.2 Scanning Electron Microscopy (SEM) Analysis



(a) Untreated (b) Treated

Fig.6. SEM of untreated and treated CH soil



(a) Untreated (b) Treated

Fig.7. SEM of untreated and treated CL soil

5 Conclusion

Based on the experimental results the following conclusions can be drawn:

- MICP was found to increased the unconfined compressive strength of both the CH (1.15 times to 1.99 times) and CL type of soils (1.19 to 1.96 times).
- It was also observed that strength increased with increase in curing duration.
- As the curing time increases to 7 days the highest value for unconfined compressive strength was achieved.
- MICP was found to increase the cohesion of soil. Improve strength characteristics and it can be match up with other properties and possible indication will guide to reduced permeability and increased bearing capacity of soil.
- MICP can be effective in cost also, as it can be produced in huge quantity at a very minimal price. Bacterial solution can be prepared in huge amounts at very low costs and cementing reagents are very economical compared to other soil improvement techniques.

References

1. Al Qabanny, A., Soga, K., Santamarina, C., 2012. Factors affecting efficiency of microbially induced calcite precipitation. J.Geotechn. Geo-environ. Eng. 138, 992-1001.
2. Animesh Sharma, Ramkrishnan R., 2018. Effect of Microbial Induced Calcite Precipitates on strength of fine grained soils, Perspectives in Science at Elsevier 2018.
3. Chu, J., Stabnikov, V., Ivanov, V., 2012. Microbially induced calcium carbonate precipitation on surface or in the bulk of soil. Geo-microbiol. J. 29 (6), 544-549.Author, F., Author, S., Author, T.: Book title. 2nd edn. Publisher, Location (1999).
4. DeJong, J.T., Fritzges, M.B., Nüsslein, K., 2006. Microbial induced cementation to control sand response to undrained shear. J.Geotechn. Geo-environ. Eng. 132 (11), 1381-1392.
5. Greene, E.A., Hubert, C., Nemati, M., Jenneman, G.E., Voor-douw, G., 2003. Nitrite reductase activity of sulphate-reducing bacteria prevents their inhibition by nitrate-reducing, sulphide-oxidizing bacteria. Environ. Microbial. 5 (7), 607-617.
6. Harkes, M.P., Van Paassen, L.A., Booster, J.L., Whiffin, V.S., 2010.Fixation and distribution of bacterial activity in sand to induce carbonate precipitation for ground reinforcement. Ecol. Eng. 36(2), 112-117.
7. Karol, H. R. (2003), Chemical grouting and soil stabilisation. 3rd edition. Marcel Dekker, Inc., New York
8. Lee Min Lee, Ng Wei Soon, Tan Chew Khun, Hii Siew Ling, 2012.Bio-mediated soil improvement under various concentrations of cementation reagents. Appl. Mech. Mater. 204-208 (2012),326-329.
9. Ng Wei Soon, Lee Min Lee, Tan Chew Khun, Hii Siew Ling,2013. Improvements in engineering properties of soils through microbial-induced calcite precipitation. KSCE J. Civ. Eng. 17 (4),718-728.
10. Siddhartha Mukherjee, R. B. Sahu, JoydeepMukherjee, Suchandra Sadhu.,2016. Application of Microbial Induced Carbonate Precipitation for Soil Improvement via Ureolysis, Indian Geotechnical Conference IGC 2016.
11. Wei-Soon Ng, Min-Lee Lee, Siew-Ling Hii, 2012. An overview of the factors affecting microbial-induced calcite precipitation and its potential application in soil improvement. World Acad. Sci. Eng.Technol. 62, 723-729.
12. Whiffin, V. (2004). "$CaCO_3$ precipitation for the production of biocement."Doctoral dissertation, Murdoch Univ., Perth, Western Australia
13. Whiffin, V.S., Van Paassen, L.A., Harkes, M.P., 2007. Microbial carbonate precipitation as a soil improvement technique Geomicrobiol. J. 25 (5), 417-423.