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Unconfined Compressive Strength of MICP Treated Black Cotton Soil by using Pseudomonas putida

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Abstract. In recent years, Microbial Induced Calcite Precipitation (MICP) technique is widely used in geotechnical engineering. The microbes produces calcite through its metabolic activities when provided with cementation solution (urea and calcium chloride). This process is capable for altering engineering as well as physical properties of highly expansive soil or black cotton soil. The present paper studied the natural microbial biological processes within black cotton soil matrix. Microbially induced calcite precipitation was achieved using the microorganism *Pseudomonas putida, NCIM 2872* equivalent to *ATCC 12842.* The microbes were introduced to the soil specimen in a liquid growth medium enhanced with cementation solution (urea, calcium chloride, nutrient broth, sodium bicarbonate and ammonium chloride). The amount of microbial medium was taken in different percentages as 5%, 10%, 15% and 20%. The soil samples were kept for different reaction periods (0 day, 7 days and 14 days). The unconfined compressive strength (UCS) of MICP treated soil were examined. From the study *Pseudomonas putida* had shown major influence for all percentages of microbes, cementation solution and reaction times on unconfined compressive strength of black cotton soil. The highest improvement in MICP treated UCS was achieved 487 kN/m^2 when soil sample was prepared with 15% microbial medium with 0.25 M cementation solution for 7 days reaction period.

Keywords: black cotton soil; MICP; Pseudomonas putida, soil stabilization; unconfined compressive strength.

1 Introduction

Black cotton soil exhibited, medium to high compressibility and plasticity, high shrinkage and swelling properties. Black cotton soil causes many problems in structures that come into their contact. In order to avoid damage, geotechnical properties are required to be investigated before allowing any construction on it. Due to weird characteristics of Black Cotton Soil, it forms a very poor foundation material. Several ground improvement methods are available in literatures viz., use of waste materials, chemical stabilization, cement stabilization, soil replacement, grouting stabilization. These techniques are time consuming, expensive and in case of grouting and chemical stabilization, they are environmental detrimental. Therefore there is need for developing a new stabilization technique that is economical and environmentally sustainable. Bio-mediated ground improvement is a relatively new and innovative environment friendly method used in recent years for mitigating geotechnical problems. This is technically termed as Microbially Induced Calcite Precipitation (MICP), to produce calcite in soil matrix. This calcite is responsible for improving engineering properties of soil. The MICP process has two major applications bio-clogging and bio-cementation. Bio-cementation is a process in which the microbially induced calcite binds the soil particles to improve its strength. Bio-clogging is used to block the pores in the soil and hence reduce the hydraulic conductivity of the soil (Wath and Pusadkar, 2019). Calcite precipitation can be achieved by different processes, urea hydrolysis, denitrification, sulphate reduction, aerobic oxidation. Literature suggests that urea hydrolysis possesses the highest calcite production rate compared to other studied processes. Calcite induced by bacteria in MICP is by hydrolysis of urea. Bacteria uses urea as an energy source and produces ammonia which increases pH in the environment, causing Ca^{2+} and CO_3^{2-} to precipitate as $CaCO_3$.

Shirakawa *et al.* (2011) studied the effect of culture medium on biocalcification by *Pseudomonas putida* INQCS 113. The results showed that calcite precipitation by *Pseudomonas putida had* good potential for the treated soil to be used as building materials. Bai Y. et al. (2017) conducted experimental research on MICP by *Pseudomonas aeruginosa* ATCC 7700. Results revealed that produced calcite extremely changed biofilm structures and distribution of calcite precipitation produced in situ was highly heterogeneous in biofilms. Present study deals with the effect of MICP on black cotton soil by *Pseudomonas putida*. The effect of MICP on UCS of black cotton soil under various conditions, reaction period and bacterial concentration were studied.

2 Materials and Methods

2.1 Soil

Soil sample collected from Amravati (Maharashtra, India) was used for the present study. The physical and engineering properties and soil classification are shown in Table 1. As per IS soil classification system, the present soil is classified as CH i.e. clay of high compressibility. The soil had higher liquid limit and plasticity index. Also, the swelling pressure and Atterberg limits indicate that the present soil is highly expansive. The soil was compacted at OMC for determination of UCS. The UCS of black cotton soil compacted at OMC was found to be 257 kN/m^2.

2.2 Microorganism

The microorganism used in the study was Pseudomonas putida. It was procured from National Collection of Industrial Microorganisms (NCIL), Pune. The strain number NCIM 2872, is an equivalent strain of ATCC 12842. Nutrient medium for the microbial culture was followed according to ATCC specifications of 20g/L yeast extract, 10g/L ammonium sulphate in 1L of 0.13M Tris buffer (pH 9.0).

2.3 Cementation solution

Cementation media was used to provide chemical compositions for ureolysis, including urea, $CaCl_2 \cdot 2H_2O$, NH_4Cl, $NaHCO_3$, and nutrient broth (Qian Zhao *et al*. 2014, Mortensen *et al*. 2011, Stocks-Fischer *et al*. 1999). Table 2 shows the chemical compositions of cementation solution for bacteria experiments. The molar ratio of urea and calcium chloride was fixed as 1:1. Cementation solution preparation method was adopted as per studies (Wath and Pusadkar, 2020)

Table 1. Properties of soil sample

Description	Value
Free swell Index	109%
Specific Gravity	2.42
Liquid limit	88%
Plastic limit	43.33%
Plasticity Index	44.67%
Shrinkage Limit	7.52
Maximum Dry Unit Weight	1.44gm/cc
Optimum Moisture Content	29%
Swelling Pressure	175 kN/m^2
Unconfined Compressive Strength	257 kN/m^2
Soil Classification as per IS	CH

Table 2. Details of Cementation Solution Concentrations

Chemical	Chemical Concentration (g/L)
	0.25 M
NH_4Cl	10.00
$NaHCO_3$	2.12
Nutrient Broth	3.0
Urea	15.0
$CaCl_2 \cdot 2H_2O$	27.8
pH	6.0

2.4 Methodology

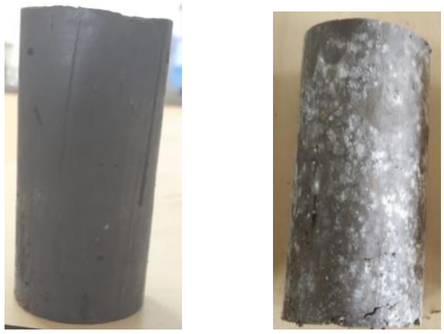
Initially adequate amount of water and the incubated bacteria was added to the soil and mixed proportionally, which was followed by mixing of the cementation solution. The uniformity mixing of soil and bacterial solution was obtained through hand mixing. Uniform mixing was ensured for proper fixation and distribution of bacteria in soil (Wath and Pusadkar 2020). The amount of bacteria was 5%, 10%, 15% and 20% by weight of soil and cementation solution was fixed as 100 ml. Soil was compacted and unconfined compression strength (UCS) tests were performed on MICP treated soil samples according to IS: 2720 (Part X). To investigate the effect of treatment duration or reaction period, MICP treated samples were allowed to react for 0, 7 and 14 days before unconfined compression tests. The samples were kept into desiccator at room temperature (28-35^{0}C).

3 Results and Discussion

To quantify the strength imparted into the MICP-treated black cotton soil under different reaction period, bacterial concentration, unconfined compression strength (UCS) tests were conducted on cemented specimens 38 mm in diameter with a selected diameter to height ratio of 1:2.

3.1 Effect of MICP on stress-strain behavior

UCS tests of present soil for different bacterial concentration and reaction period were conducted to understand its effect. The soil samples of UCS test were prepared by static compaction method. The soil was treated with bacteria and then compacted. After compaction the sample was removed from mold and then it was placed for a particular period for growth of bacteria and calcite precipitation. Fig. 1 (a) shows soil sample without treatment and (b) shows the precipitation of calcite on soil sample after treatment. The white formation on soil surface indicates the calcite formation on the soil compacted at OMC. The stress-strain curve obtained from UCS tests for soil treated with different bacterial concentration with zero day reaction periods are shown in Fig. 2. The specimen treated with 10% bacterial concentration resulted in highest peak strength whereas, 5% bacterial concentration gives result slightly similar with 10%.



(a) Untreated (b) Treated

Fig. 1. Soil Sample without and with treatment

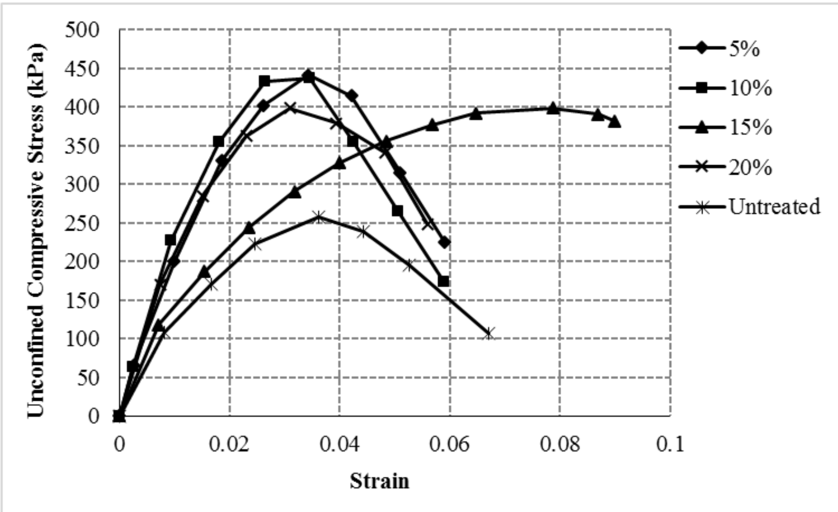


Fig. 2. Stress-strain relationships of soils treated under different bacteria concentration for 0 day reaction period

Fig. 3 shows the stress-strain curve for soils treated with 15% bacterial concentration for different reaction period. The maximum strength was observed for 7 day reaction period. The improvements in UCS of microbial treated soil is significant than that of untreated soil. The failure pattern of microbial treated soil is found to be brittle failure at low strain.

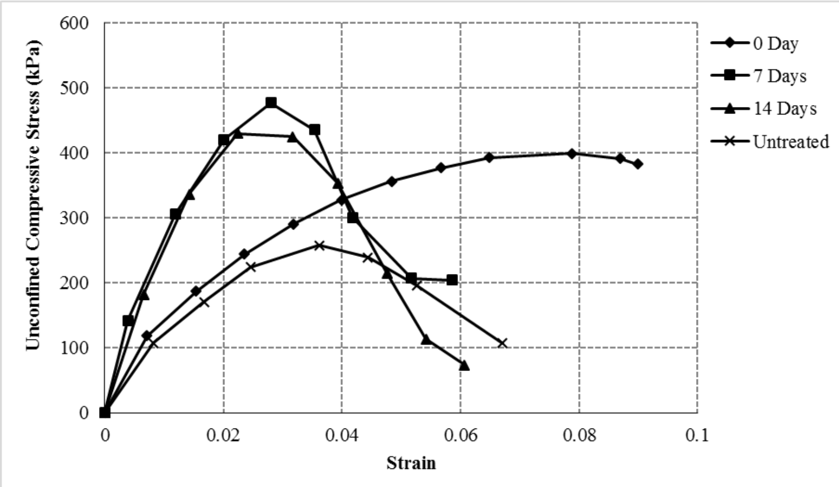


Fig. 3. Stress-strain relationships of soils treated under 15 % bacteria concentration for various reaction period

The unconfined compressive strength for each case was determine and shown in Table 3. The unconfined compressive strength of microbial treated black cotton soil was found to be increased by 1.6 to 1.94 times that of untreated soil. This is significant improvement in the UCS. Even for 5% bacterial concentration and zero day reaction periods, the UCS was increased by 178%.

Table 3. UCS under different bacterial concentration and reaction period

Reaction Period (d)	Bacterial Concentration (%)				
	0%	5%	10%	15%	20%
0	257	447	449	399	413
7	-	421	347	487	459
14	-	439	420	445	443

3.2 Effect of reaction time

Microbial induced calcite precipitation through bacteria is a complex biochemistry and transient process (Zhao, *et al.*, 2014). The reaction time is one of the influencing factor for the MICP. MICP-treated soil samples were prepared and kept in air tight chamber for 7 and 14 days to study the influence of reaction time on soil strength. The UCS was also test immediately after the preparation of soil sample i.e. zero day reaction period. Fig. 4 shows variation of UCS with reaction period. The UCS for sample with low bacterial concentration found to be maximum even for zero reaction period while for higher bacterial concentration the maximum UCS was found for seven day reaction period. Hence, it can be said that for lower concentration of microbial, the UCS can be improved immediately after mixing soil with bacteria.

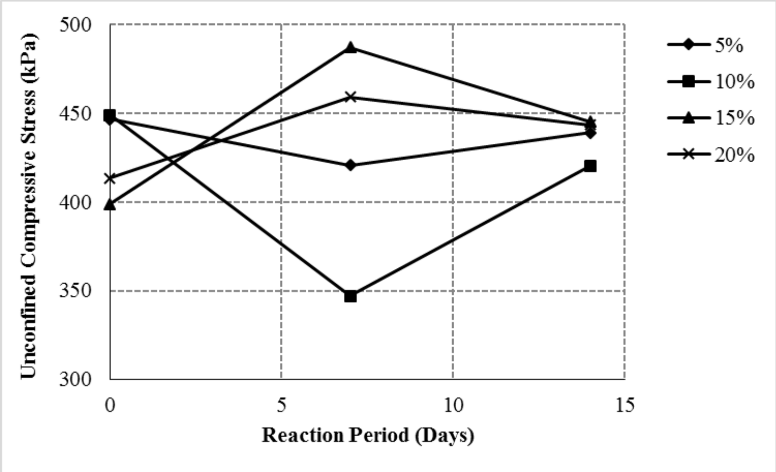


Fig. 4. Stress-reaction period relationships of soils treated under different reaction period

3.3 Effect of Bacterial Concentration

The black cotton soil was treated with four different bacterial concentration catalyzed by Pseudomonas putida as shown in Fig. 5. As the bacterial concentration increases, UCS increases for all bacterial concentration as compared to untreated soil. The maximum strength was observed for 15% bacterial concentration, almost 94% increase in UCS. However even with 5%, bacterial concentration, UCS increases by 79%. These findings indicates that bacteria plays an important role in calcite precipitation and improving the soil strength. The improvement in UCS with 5% bacterial concentration shows that it can be recommended for microbial treatment even though higher % had more UCS. This recommendation is due use of lower bacterial concentration and achieving higher UCS saving time, material and money also.

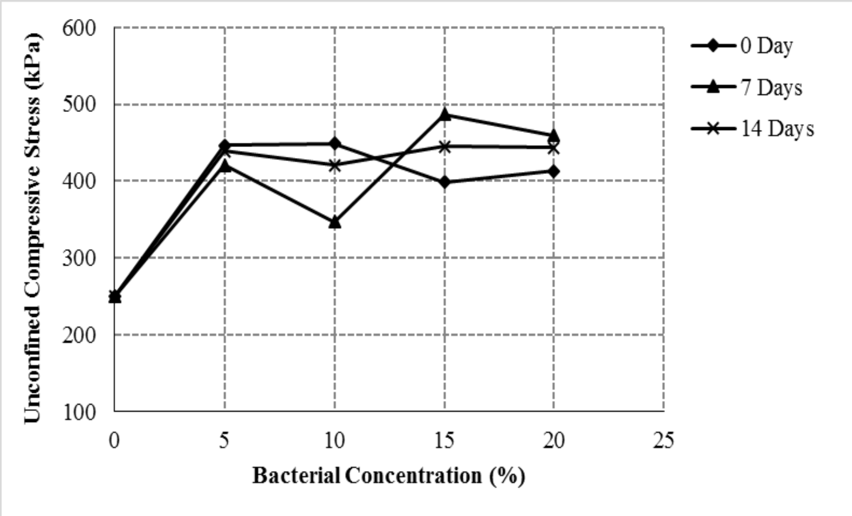


Fig. 5. Stress-bacterial concentration relationships of soils treated for various bacterial concentration

4 Conclusions

A series of laboratory tests were performed to investigate effectiveness of MICP in improving unconfined compressive strength of black cotton soil by Pseudomonas putida. From the present study, following conclusions are drawn.

1. Pseudomonas putida is found to be effective for the stabilization of black cotton soil.
2. The unconfined compression strength of MICP treated specimen increases for all bacterial concentrations than untreated soil.
3. The unconfined compressive strength of MICP treated specimen increases with all reaction period. The treated soil base for roads will enhance the performance of the pavement.
4. 5% bacterial concentration with 0 day reaction period gives most favorable result.
5. The use of MICP as a stabilization method for black cotton soil would be green, sustainable, eco-friendly technique.

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