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IMPROVEMENT OF SOIL BEHAVIOR BY MICROBIAL INDUCED CALCITE PRECIPITATES

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Abstract:

Nowadays, the recent development of cities leads to construction of many high rise buildings which needs a strong and good foundation. So, it is important to improve the properties of soil. The process of improving the properties of soil is known as soil stabilization. In recent days, chemical methods are widely used for treating soil to improve the properties. In addition to that of chemical methods, an attempt has been made using micro-organisms, nutrients that are naturally present in subsurface soil which precipitate calcites to improve the engineering properties of soil in sustainable way. In this process, a species *bacillus*group, *B.megaterium* was used to activate and catalyze the calcite precipitation by adding reagents to it. This is made on the soil sample that had taken from Pachapalayam, Coimbatore. The concentration of cementation reagents and duration of treatment are the two parameters included in this project. The results in this project showed that with the use of MICP (microbial induced calcite precipitates), there was an increment in strength of soil. However, to adopt the microbial methods effectively, microbiological, ecological studies and design considerations are required.

Key Words: Soil Stabilization, B. Megaterium, Calcite Precipitation, Cementation Reagents & MICP

1. Introduction:

Stabilization is one of the soil modification techniques to improve its engineering performance. Dramatically increased construction activities demands more area which leads to scarcity of land with proper strength characteristics of sand. This technique aimed at increasing or maintaining the stability of soil mass and chemical alteration of soils to enhance their engineering properties. Stabilization can be used to treat a wide range of sub-grade materials from expansive clays to granular materials. Benefits of the stabilization process can include higher resistance values, reduction in plasticity, lower permeability, and reduction pavement thickness. In general, many methods are in practice for soil stabilization and to improve soil behavior. Conventional techniques such as applying cement or chemicals are primarily used to improve soil; however these can leadto permanent soil and water contamination or air pollution. This experiment was to perform a feasibility study concerning use of microbial induced calcite precipitation to strengthen the problematic soil by bio-cementation. MICP has an attractive method of grouting to improve the soil structure. The induction of $CaCO_3$ precipitation binds sand grains together as the particle- particle contact, which increases the strength and stiffness of the soil. The applications of this method shows potential in various fields like improvement of strength of soil and various works are being conducted on these fields in the current scenario. In this MICP process urease plays a major role in urea hydrolysis by a wide verity of microorganisms capable of producing high levels of urease. This MICP is a promising, eco friendly alternative up roach to conventional and current remediation technologies to solve environmental problems in multi-disciplinary fields.

2. Microbially Induced Calcite Precipitation:

Microbial induced calcite precipitation (MICP) is a new, green and sustainable technique which has been introduced in the field of ground improvement. Many researchers studied that effect of MICP on soil (sandy soil) has improved their shear strength and reduced hydraulic conductivity. Previously, the formation of calcium carbonate precipitation was proposed to occur via different mechanisms such as photosynthesis, urea hydrolysis, sulfate reduction, anaerobic sulfide oxidation. However, the precipitation of calcium carbonate by bacteria via urea hydrolysis is the most widely used method. The urease enzyme, supplied directly into soil produced in situ by bacteria, decompose urea ($CO(NH_2)_2$) in the soil through a chemical reaction known as hydrolysis of urea.

$$CO(NH_2)_2 + 2H_2O^- \xrightarrow{\text{urease}} 2\,NH_4^+ + CO_3^{2-}$$

The ammonium (NH_4^+) released from urea hydrolysis results in local pH rise and commences the precipitation of calcium carbonate. The high pH at localized area increases the tendency for bacteria itself to serve as nucleation site for calcite crystal. Calcite is precipitated through the combination of carbonate ions (CO_3^{2-}) from the hydrolysis of urea and the calcium ion (Ca^{2+}) from supplied calcium chloride:

$$Ca^{2+} + CO_3^{2-} \longrightarrow Ca\,CO_3$$

The calcite ($CaCO_3$) generated from the chemical reactions is responsible for the biocementation and bioclogging of soil specimens. Many bacteria are capable of producing urease enzyme from their microbial activity. The calcite precipitation process depends essentially upon four elements: calcium ion concentration dissolved inorganic carbon (DIC) concentration, pH, and availability of nucleation sites. Nevertheless, the environmental conditions (e.g. salinity, temperature, nutrient, etc) also have their influences on MICP performance.

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3. Material Properties:

Soil sample used in this experiment were collected from Pachapalayam, Coimbatore. The basic properties of soil samples were determined as per IS codes and are shown in table 1.

Table 1: Soil Sample- Basic Properties

Description	Symbol	Values
Gravel	G	7.6%
Sand	S	90.6%
Silt + clay	M + C	1.8%
Liquid Limit	W_L	26.5

3.2 Bacteria for Calcite Precipitation: The bacteria that are used for calcite precipitation are should be Urease positive bacteria. Some of the Urease producing and calcite precipitating bacteria that can be used are *Bacillussp. CR2, L.sphaericus CH5, Sporosarcinapasteurii, B.pasteurii NCIM 2477, K.flava CR1, B.megaterium SS3, B.thuringiensis, Halomonassp.SR4.* The bacteria used in this study was *B.megaterium,* which is gram positive and Urease producing bacteria. The concentration of *B.megaterium* was $1x10^{10}$ cfu/ml and shown in fig.1.

3.3. Cementation Reagents: The following chemicals were added to make the cementation reagents: 10g of NH_4Cl, 2.12g of $NaHCO_3$, 20g of Urea, 185g of calcium chloride and 3g of Nutrient broth were added to 1liter of distilled water solution. Concentration of cementation reagents was a governing parameter was varied as 0.25M, 0.5M, 0.75M.

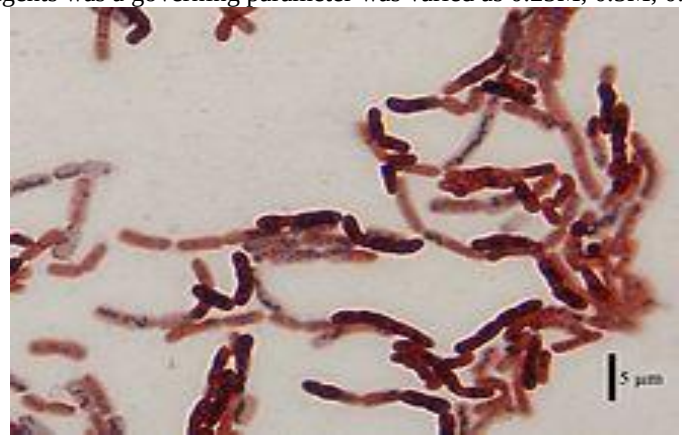

Figure 1: Bacillus Megaterium

3.4 Mixing and Curing: Initially bacteria was added to the soil and mixed properly, followed by addition of cementation reagent. The bacteria, cementation reagent and treatment duration were varying parameters. The soil samples were allowed for curing of 0, 3 and 7 days. Proper mixing was ensured for proper fixation and distribution of bacteria in soil sample. The samples were kept under maintained temperature of 20°C to 30°C, through a combination of moist sand and moist gunny bags. Unconfined compression test were performed on soil sample as per IS 2720 (part 10) and the tested soil samples were dried and used for performing free swell index test.

4. Results and Disscussions:

4.1 Test Results - UC Tests: The UCS value for virgin soil sample was $0.99kg/cm^2$, which on treatment with MICP was found to increase further. The test results of soil sample are tabulated in Table2. It was observed from the test results that by increasing the treatment duration, UCS value further increased. The result shows that the highest increment of strength of soil for 0.5M of cementation reagent. This shows that equal moles of bacterial concentration and cementation reagent gives highest increment of strength parameter of soil. And also showed that when curing period was increased then the unconfined compressive strength increased from $1.02kg/cm^2$to $2.54kg/cm^2$.The UCC test apparatus setup is shown in fig 2. The stress strain variations of soil with different concentration are shown in Fig.3-5.

Table 2: Unconfined Compressive strength (UCS)

Bacteria	Cementation reagents	0 days		3 days		7 days	
		Soil Sample	UCS Kg/cm^2	Soil Sample	UCS Kg/cm^2	Soil Sample	UCS Kg/cm^2
Bacillus megaterium $1x10^{10}$ cfu/ml	25%	A_1	1.12	B_1	1.68	C_1	2.16
	50%	A_2	1.52	B_2	1.96	C_2	2.45
	75%	A_3	1.36	B_3	1.74	C_3	2.31

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Figure 2: UC test

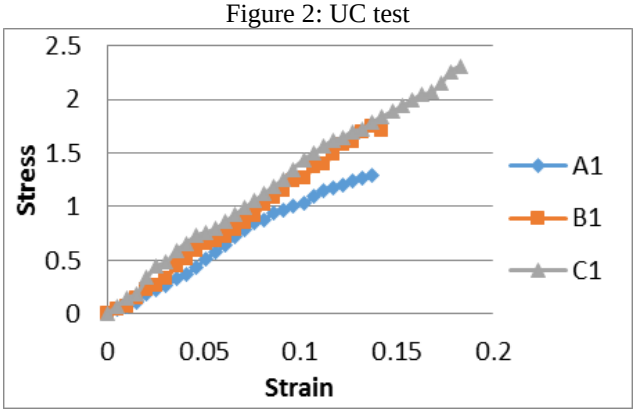

Figure 3: UCS value for 25% of cementation reagent @ 0 days, 3 days, 7 days.

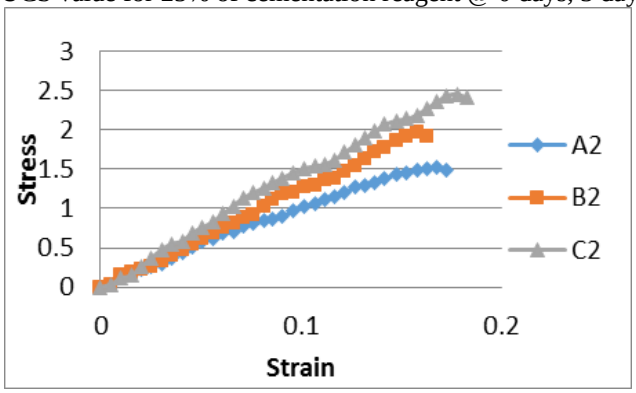

Figure 4: UCS value for 50% of cementation reagent @ 0 days, 3 days, 7 days

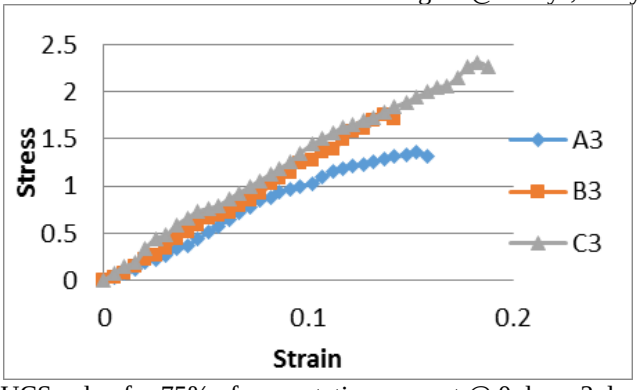

Figure 5: UCS value for 75% of cementation reagent @ 0 days, 3 days, 7 days.

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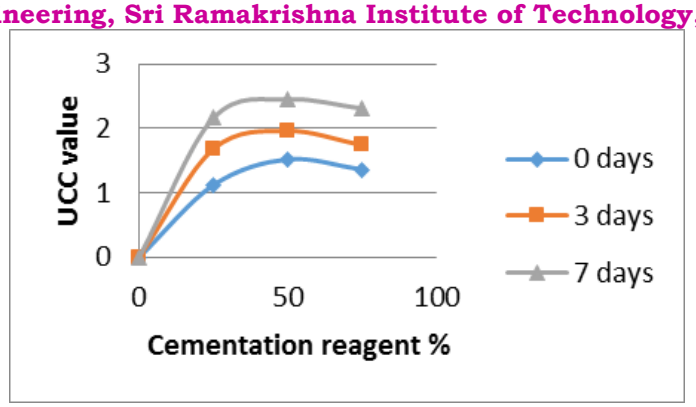

Figure 6: UCS value for 25%, 50%,75% of cementation reagent @ 0 days, 3 days, 7 days.

From the above Fig.6 it is clearly shown that the UCS value is high when equal moles of cementation reagent and bacteria are added.

5. Conclusion:

The results shown that the MICP was found to increase the unconfined compressive strength value of the soil sample from 1.02 kg/cm^2 to a highest value of 2.45 kg/cm^2 which is about 2.5 times and also found that the strength increased by increasing curing duration. More particle to particle interaction caused the soil matrix to bond with the calcite precipitates firmly. This led to denser packing of the soil composite. This will further lead to increased bearing capacity, minimized settlements, reduced permeability of soil and reduction in development of pore pressure. Though there are many urease positive bacteria, it is suggested to use *sporosarcina pasteurii*, *B.megaaterium B.thuringiensis* which have the greatest potential in microbial induced calcite precipitate production. Many researchers have developed various conventional methods for environmental clean- up, but these method are in efficient and expansive. MICP is used in various fields like stabilizing soil, reinforcing soil enhancing stability for retaining walls, embankment and dams. Though the MICP has many merits, further study is needed to overcome the limitations to use of this technology prior to its commercialization.

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