

Study on Improvement of Soil Behaviour by Bio-Stabilisation Method

N. Kamaraj, V. Janani*, P. T. Ravichandran, D. Nigitha and K. Priyanka

Department of Civil Engineering, SRM University, Kattankulathur - 603203, Tamil Nadu, India;
n.kamaraj@yahoo.com, jananivijayarajan@gmail.com, ptrsrm@gmail.com,
nigitharajan@gmail.com; priyakoraganji@gmail.com

Abstract

Background/Objectives: In India the increase in population and industrialisation, there is a much need for the soil to be used for various activities. There is a need to improve the properties of soil, if the soil at any particular locality is unsuited, wholly or partially selected for the construction. With increasing awareness of environmental issues, there has been a remarkable shift toward “green” and sustainable technologies. In view of these attempt is made to study the new sustainable method of biogeochemical techniques to improve the soil properties. **Methods:** In this work test for the Unconfined Compressive Strength (UCS) for soils were conducted as per IS to know variation in strength characteristics with the addition of two bacteria namely *Acetobacter* and *Bacillus* of different incubation periods and curing periods. For the same soil samples, the free swell index values were also determined to know the effect of addition of bacteria by stabilisation. **Findings:** The UCC test results for the soil samples treated with bacteria showed an increase in strength of soil with the increase in age of bacteria. The increase in Unconfined Compressive Strength (UCS) value at 60 day curing period is about 175% for soil treated with *Acetobacter* and 520% for *Bacillus*. Swelling characteristics also reduced by the treatment with *Acetobacter* and *Bacillus* bacteria. **Improvement/Applications:** Biostabilisation with bacteria proved the increase in strength and decrease in swell it can be used as an innovative stabiliser for stabilising problematic soils, which is cost-effective, non intrusive, low energy demanding and ecofriendly.

Keywords: Bio-Stabilisation, Bacteria, Free Swell, UCS

1. Introduction

Stabilization is one of the soil modification technique is for modifying the properties of a soil to improve its engineering performance. Dramatically increased construction activities demands more area, and final outcome was scarcity of land with proper strength characteristics. In all the geotechnical works, it is impossible to locate a construction site that with proper design requirements. Mostly, the sites with unsuitable soil are modifying by the various ground modification methods to change its engineering properties to meet the design necessities. Stabilization is being used for a variety of geotechnical works and its main objective is to increase the soil stability of to reduce the construction cost by making best use of locally available materials¹⁻⁴. Major problematic soil in

India are Expansive soils, have the tendency to change its volume, it causes many problems in structures that come into their contact or constructed out of them. In general physical, chemical, mechanical, or combined method of changing the behaviour of natural soil is used for stabilisation. As conventional method of stabilization, the use of waste materials such as Fly Ash (FA), Bagasse Ash (BA) and Rice Husk Ash (RHA) shows the significant improvement in the engineering characteristics of soil by means of change in microstructural arrangement leads to cementation⁵⁻⁸. Stabilization of expansive soils with different chemical additives like lime, gypsum, cement, flyash⁹⁻¹³ etc, as additives also stabilised the soil and modify its properties to improve its strength include increasing the weight bearing capabilities in order to attain the stability of soil.

*Author for correspondence

This study was to perform a feasibility study concerning the use of Microbial Induced Calcite Precipitation to strengthen the problematic soil by Bio-cementation. The problematic soil used is expansive soil, which has high swelling, high compressibility properties and low bearing capacity. The laboratory tests were conducted to know the study the influence of Microbial Induced Calcite Precipitate Bacteria on Swelling, Strength properties and Microstructural Analysis with effect of aging in bacteria and with different curing periods.

2. Material Properties

Soil sample were collected from Chennai, used in this study was the problematic soil and Microbially Induced Calcite Precipitation (MICP) Bacteria - *Acetobacter* and *Bacillus* at different concentrations (10^{-6} and 10^{-7} cfu/ml) incubated for 1 and 4 days were used to enhance the strength characteristics and to minimise the swell characteristics of the soil. The engineering properties of the soil were determined as per BIS¹⁴⁻¹⁶ are shown in the Table 1. The sieve analysis results showed 13% sand, 29% of silt content and 58% particles smaller than 0.002 mm (clay), based on the Atterberg's limits¹⁷ the soil was classified as CH (High Compressible Clay). Compaction characteristics were also conducted for soil sample to determine the OMC and MDD¹⁸ and the chemical compositions of soil are given in Table 2. Microstructural analysis was carried out by Scanning Electron Microscopy (SEM), together with chemical analysis to identify the minerals present on the soil and also its changes due to influence of bacteria after treatment.

Table 1. Properties of soil sample

Parameter	Symbol	Value
Specific gravity	G	2.47
Liquid limit	W_L	52%
Plastic limit	W_p	20.7%
Plasticity index	I_p	31.3
Shrinkage limit	W_s	8.5
Free swell Index	FI	75%
Standard Proctor	OMC	W
	MDD	γ_d
Unconfined Compressive Strength (UCS)	q_c	1.66kg/cm ²
California Bearing Ratio	CBR	5.8%

3. Results and Discussion

3.1 Unconfined Compressive Strength (UCS) Test

Soil specimens for unconfined compressive strength test¹⁹ were prepared by static compaction with the corresponding MDD and OMC of the stabilized soils had been determined from standard compaction test. The tests was conducted for virgin soil and the soil treated with different concentrations of *Acetobacter* and *Bacillus* bacteria immediately after the sample preparation and the remaining specimens were tested after 1, 3, 7, 14, 28 and 60 days. The stress- strain variations of soil with different concentrations of MICP bacteria are shown in Figures 1-3.

In compressive strength, MICP yields dominant enhancement for the natural soils with the increase in age of MICP bacteria and this can be shown in Table 3. When the curing period was increased then the Unconfined Compressive strength increased from 28.3 to 110% for *Acetobacter* and for *Bacillus* it increased from 37% to 250% with same concentration. The increment of incubation period increases the growth of bacteria leads to the formation of calcium precipitation which induces

Table 2. Chemical composition of soil

Chemical Constituents	Chemical Composition %
Silica	67.09
Alumina	11.47
Calcium oxide	0.87
Magnesium oxide	1.88
Ferric oxide	6.22
Sodium oxide	1.14

Table 3. UCS values of soil treated with MICP bacteria for various curing periods

Bacteria	Age of bacteria (days)	Dilution factor (cfu/ml)	Curing period (days)				
			1	7	14	28	60
<i>Acetobacter</i>	1	A1	2.13	2.3	2.46	2.59	3.49
		A2	1.84	1.86	2.27	2.55	2.98
	4	A1	2.3	2.52	2.87	4.17	4.56
		A2	2.15	2.34	2.48	2.92	3.39
<i>Bacillus</i>	1	B1	2.28	2.59	2.72	2.82	5.82
		B2	2.15	2.46	2.67	2.72	5.24
	4	B2	2.28	3.14	4.52	6.21	10.45

*A1 and B1 = 10^{-6} cfu/ml, A2 and B2 = 10^{-7} cfu/ml and A3- 10^{-8} cfu/ml

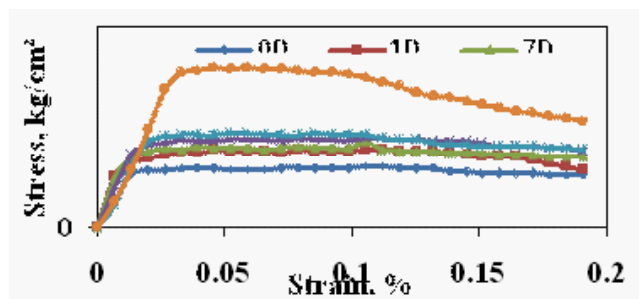


Figure 1. Stress strain behaviour of soil treated with 1 day age of *Acetobacter* bacteria (10^{-6} cfu/ml).

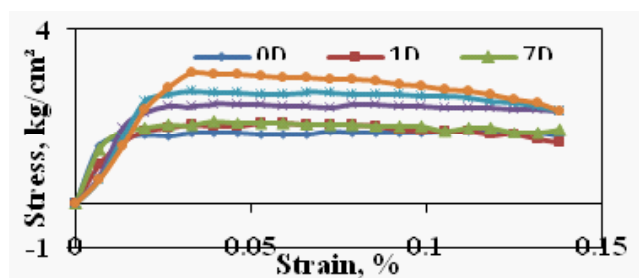


Figure 2. Stress strain behaviour of soil treated with 1 day age of *Acetobacter* bacteria (10^{-7} cfu/ml).

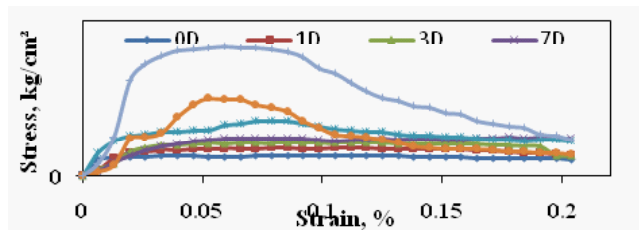


Figure 3. Stress strain behaviour of soil treated with 4 day age of *Bacillus* bacteria (10^{-7} cfu/ml).

the cementation. The rate of increase of UCS test results are increasing gradually up to 28 days and after 28 days there is a rapid increase in the long term curing period due to Calcium precipitation. It is observed that *Bacillus* achieved better results than *Acetobacter* in the increasing incubation period with related to the higher concentration. This increment is because of increase in the growth of bacteria which promotes the reaction rate of soil.

3.2 Free Swell Index Test

The Free Swell Index test recognises the swell characteristics of soil samples for evaluating the expansive nature of soils. This test were conducted on the treated and raw soil

samples as per IS: 2720 (Part-40) specification²⁰. After the UCC tests, the samples are dried and powdered and used for Free Swell Index tests. The test results of the Free Swell Index for the soil samples treated with varying concentrations of *Acetobacter* and *Bacillus* bacteria for varying curing period are given in Table 4. The results, shows that, as the age of bacteria increases, the swell decreases with increase in curing period of the treated soil samples. The percentage of decrease is more for the soil treated with 4 day age of *Bacillus* bacteria than with the soil treated with *Acetobacter* bacteria.

4. Microstructural Analysis

The microstructural analysis was conducted on the untreated and bacteria treated soil samples in order to understand the microscopic behaviour and physical properties of soils. The improvement in treated soils are studied based on the results obtained from Scanning Electron Microscopy method.

SEM micrographs are observed on samples obtained by pulverising the tested UCC samples. Figure 4 shows the typical SEM micrographs of virgin samples, admixture and treated sample at a curing period of 60 days. From the micrographs, it was noticed that the distribution of particle assemblies and pores in virgin samples are bonded by cementitious compounds when compared with the treated soil samples.

The XRD was conducted on powderedly treated samples to examine the orientation of minerals. The X-ray diffraction diagrams for the untreated soil and treated samples with two different bacteria at one curing period are shown in Figure 5. The X-ray diffraction

Table 4. Effect of various concentrations of *Acetobacter* and *Bacillus* bacteria on FSI of the soil

Bacteria	Age of bacteria (days)	Dilution factor (cfu/ml)	Curing period (days)				
			1	7	14	28	60
<i>Acetobacter</i>	1	A1	70	65	58	55	50
		A2	70	65	60	55	50
	4	A1	65	60	55	50	40
		A2	65	55	50	50	45
<i>Bacillus</i>	1	B1	70	60	55	50	45
		B2	70	65	55	50	45
	4	B2	65	55	50	45	40

*A1 and B1 = 10^{-6} cfu/ml, A2 and B2 = 10^{-7} cfu/ml

can be used for understanding and quantitative determination of the various crystalline compounds present in soil sample.

XRD results of untreated and treated sample at two different concentrations were examined in order to identify the modification in its mineralogical structure indicating the changes based on curing periods. From the XRD results it is detected that most crystalline phases are decreased, meaning that more development of

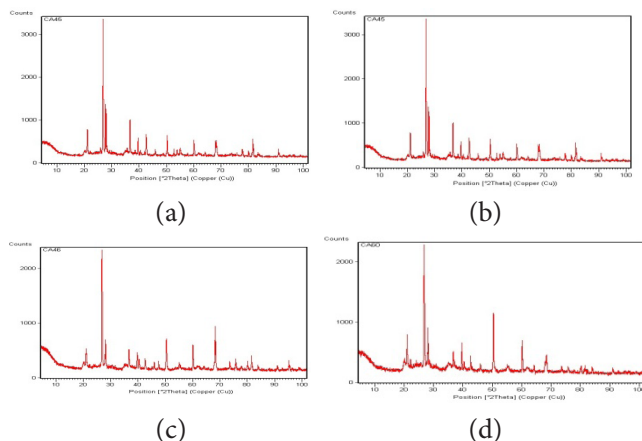


Figure 4. XRD pattern of untreated soil and treated soil with different incubation periods and concentrations of *Acetobacter* and *Bacillus* bacteria. (a) Untreated soil. (b) Soil treated with 1 day *Acetobacter* A1 - 60 days curing period. (c) Soil treated with 1 day *Acetobacter* A2 - 60 days curing period. (d) Soil treated with 1 day *Bacillus* B1 - 7 days curing period.

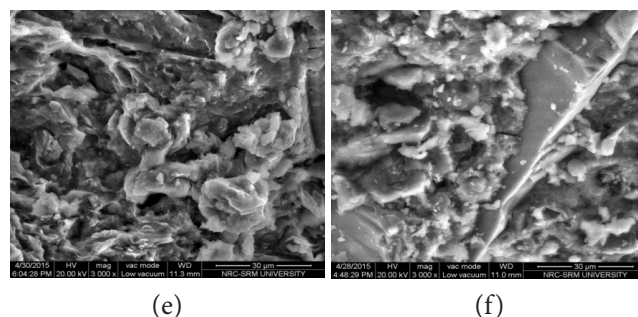
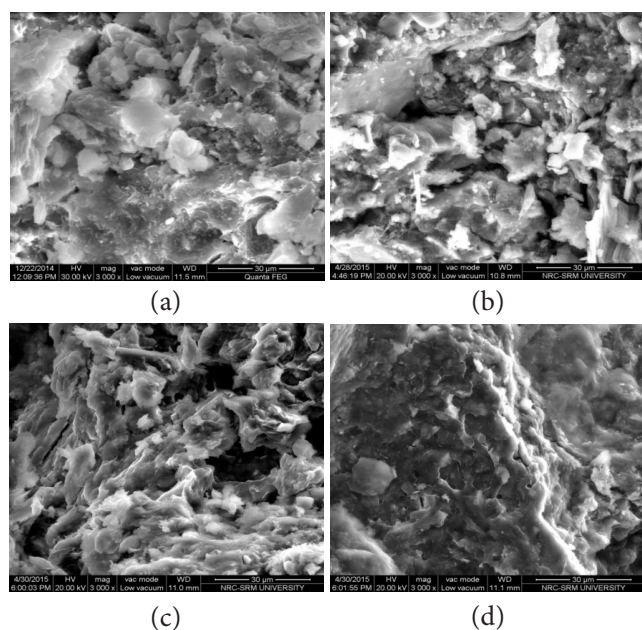


Figure 4. Micrographs of the untreated and treated soil with different incubation periods and concentrations of *Acetobacter* and *Bacillus* bacteria. (a) Untreated soil. (b) Soil treated with 1 day *Acetobacter* A1 60 days curing period. (c) Soil treated with 1 day *Bacillus* B1 60 days curing period. (d) Soil treated with 1 day *Bacillus* B2 60 days curing period. (e) Soil treated with 4 day *Acetobacter* A1 60 days curing period. (f) Soil treated with 4 day *Bacillus* B2 60 days curing period.

the bonding matrix, which is probably related with the strength increase during the treatment process.

5. Conclusion

From this study the results are observed for the strength characteristics, swell characteristics and micro structural analysis of the soil.

The Unconfined compressive strength of the soil samples stabilized with MICP bacteria yield more strength with the age and percentage of bacteria and increase in the UCS value at 60 days curing period is about 5.2 times for *Bacillus* and 1.75 times for *Acetobacter*.

The swelling characteristics also reduced by the treatment with *Acetobacter* and *Bacillus* bacteria showing FSI of 45 and 40 from 75% with 4 days aged bacteria at 60 days curing period.

Microstructural analysis shows the reduction in pore space due to the formation of calcium precipitate leads to denser soil structure with the treatment of MICP bacteria.

Biostabilisation with MICP bacteria proved as an innovative stabiliser for stabilising problematic soils, which is cost-effective, non intrusive, low energy demanding and ecofriendly method.

6. Acknowledgment

The authors sincerely acknowledge their thanks to the Nano Technology Research Centre, SRM University, Kattankulathur for the help in SEM analysis.

7. References

1. Bhuvaneshwari S, Robinson RG, Gandhi SR. Stabilisation of expansive soils using fly ash. Fly Ash Utilisation Programme (FAUP); New Delhi: TIFAC, DST; 2005.
2. Yilmaz I, Civelekoglu B. Gypsum: An additive for stabilization of swelling clay soils. *Applied Clay Science*. 2009 Apr; 44(1-2):166–72.
3. Krishnan KD, Ravichandran PT, Janani V, Annadurai R, Gunturi M. Effect of Phosphogypsum and fly ash stabilisation on the strength and microstructure of clay. *Indian Concrete Journal*. 2015 Jun; 89(7):81–6.
4. Prakash M, Jeyanthi J. Effect of rice husk ash and fly ash on engineering properties of expansive soil. *Proceedings of Indian Geotechnical Conference*; 2013 Dec. p. 1–7.
5. Okafor FO, Ugochukwu. Effects of rice husk ash on some geotechnical properties of lateritic soil. *Leonardo Electronic Journal of Practices and Technologies*. 2009 Jul–Dec; 8(15):67–74.
6. Mohammed YF, Falah HR, Kawther YH, Al Soudany. Improvement of clayey soil characteristics using rice husk ash. *Journal of Civil Engineering and Urbanism*. 2013 Jan; 3(1):12–8.
7. Kharade AS, Suryavanshi VV, Gujar BS, Rohankit R, Deshmukh. Waste product bagasse ash from sugar industry can be used as stabilizing material for expansive soils. *International Journal of Research in Engineering and Technology*. 2014 Mar; 3(3):1–7.
8. Gandhi KS. Expansive soil stabilization using bagasse ash. *International Journal of Engineering Research and Technology*. 2012 Jul; 1(5):1–3.
9. Rao DK, Pranav PRT, Anusha M. Stabilization of expansive soil with rice husk ash, lime and gypsum- An experimental study. *International Journal of Engineering Science and Technology*. 2011 Dec; 3(11):8076–85.
10. Shrivastava D, Singhai AK, Yadav RK. Effect of lime and rice husk ash on engineering properties of black cotton soil. *International Journal of Engineering Research and Science and Technology*. 2014 May; 3(2):1–4.
11. Moses G, Osinubi KJ. Influence of compactive efforts on cement-bagasse ash treatment of expansive black cotton soil. *International Science Index*. 2013; 7(7):1–8.
12. Rajkumar PRK, Krishnan KD, Sudha C, Ravichandran PT, Vigneshwaran TD. Study on the use of industrial waste in preparation of green bricks. *Indian Journal of Science and Technology*. 2016; 9(5):1–6.
13. Rajkumar PRK, Ravichandran PT, Krishnan KD, Harini TA. Study on the use of bagasse ash paver block in low volume traffic road pavement. *Indian Journal of Science and Technology*. 2016 Feb; 9(5):1–6.
14. IS: 1498, Classification and identification of soils for general Engineering purposes. New Delhi: Bureau of Indian Standards; 1970.
15. IS: 2720 (Part 3), Methods of tests for soil: Determination of specific gravity. New Delhi: Bureau of Indian Standards; 1987.
16. IS: 2720 (Part 6), Methods of tests for soil: Determination of shrinkage factors. New Delhi: Bureau of Indian Standards; 1972.
17. IS: 2720 (Part 5), Methods of tests for soil: Determination of liquid limit and plastic limit. New Delhi: Bureau of Indian Standards; 1985.
18. IS: 2720 (Part 7), Methods of tests for soil: Determination of water content-dry density relation using light compaction. New Delhi: Bureau of Indian Standards; 1980.
19. IS: 2720 (Part 10), Methods of tests for soil: Determination of unconfined compressive strength. New Delhi: Bureau of Indian Standards; 1973.
20. IS: 2720 (Part 40), Methods of tests for soil: Determination of free swell index of soils. New Delhi: Bureau of Indian Standards; 1977.