COMPARATIVE ANALYSIS OF RICE HUSK BIOCHAR AND MICROBIALLY INDUCED CALCITE PRECIPITATION IN STABILIZATION OF AN EXPANSIVE SOIL

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Abstract-*In geotechnical engineering, clayey soils with high flexibility and low strength serious difficulties, especially when building foundations and pavements. For improving their engineering properties, soil stabilization is a useful method. The current paper emphases on use of Microbially Induced Calcite Precipitation (MICP) (a bio-mediated method) and Rice Husk Biochar (RHB), an agricultural waste product, as sustainable stabilizers to enhance the behaviour of an expansive clayey soil. The effects of adding RHB in different proportions of 5%, 10%, and 15% as well as applying MICP treatment at various dosages of 2 ml, 4 ml, 6 ml, and 8 ml are the main concerns of this study. Series of laboratory tests were performed on selected native expansive soil, (soil - RHB) mixes and (soil-MICP) mixes to assess changes in index properties, compaction characteristics and strength (Unconfined Compressive Strength (UCC) and California Bearing Ratio (CBR)) laboratory experiments were performed on untreated soil. The findings show that adding RHB improves the Plastic Characteristics and reduces Maximum Dry Density (MDD) due to its porous nature. Introduction of Calcium Carbonate Precipitation to the soil, the interparticle bonding strengthen, MICP treatment considerably improves soil characteristics. This leads to a significant rise in strength parameters and a significant decrease in plasticity. With MICP, the Unconfined Compressive Strength (UCC) and California Bearing Ratio (CBR) values significantly improved, with 4 ml dosage showing the best results. MICP is proven to be more successful than RHB in increasing the soil strength, decreasing its flexibility, and increasing its load-bearing capacity. The study concludes stating conclusion that using MICP and RHB is an efficient, sustainable, and environmentally friendly method of stabilizing soil, where MICP being primarily responsible for strength enhancement and RHB for improved workability and sustainability.*

Key words- Soil stabilization; Microbially Induced Calcite Precipitation (MICP); Rice Husk Biochar (RHB); Unconfined Compressive Strength (UCC); California Bearing Ratio (CBR).

1. INTRODUCTION

Expansive soils are problematic fine-grained soils that undergo significant volume changes with variations in moisture content, swelling during wet conditions and shrinking during dry conditions. This behaviour causes severe damage to pavements and foundations in the form of cracking and differential settlement. These soils generally possess low shear strength and poor load-bearing capacity, making construction difficult without proper stabilization. Conventional stabilizers such as cement, lime, and calcium chloride effectively improve soil properties, but their usage is limited due to high cost, environmental concerns, and carbon emissions. Recently, sustainable stabilization methods using agricultural waste materials and biological processes have gained attention. Rice Husk Biochar (RHB), a carbon-rich material produced through pyrolysis of rice husk, has shown promising results in improving soil behaviour. Saberian et al. (2025), Kumar S. (2025), and Lu et al. (2021) reported that biochar improves soil structure, reduces plasticity, enhances compaction behaviour, and improves moisture retention. Chen et al. (2023) and Ranjith and Smrithi (2024) also observed improved strength and reduced cracking behaviour in biochar-treated soils.

Microbially Induced Calcite Precipitation (MICP) is another eco-friendly stabilization technique in which urease-producing bacteria precipitate Calcium Carbonate within the soil matrix, acting as a cementing agent between soil particles. Tiwari et al. (2023) reported significant reduction in swelling and improvement in Unconfined Compressive Strength (UCC) due to Calcite bonding. Wang and Konstantinou (2022) and Fu et al. (2021) also demonstrated that MICP improves soil strength and stiffness under optimized conditions. Rao et al. (2024) studied the combined use of biochar and MICP and observed enhanced strength and reduced swelling behaviour. Although both RHB and MICP have shown considerable potential in expansive soil stabilization, comparative studies under similar curing conditions are limited. Therefore, the present study aims to compare the effectiveness of RHB and MICP in improving the plasticity characteristics, compaction behaviour, Unconfined Compressive Strength (UCC), and California Bearing Ratio (CBR) of expansive soil under curing periods of 0, 3, and 7 days.

2. MATERIALS AND METHODOLOGY

2.1 MATERIALS

2.1.1 Expansive Soil

The expansive soil was collected from a natural site at a depth of approximately 2.0 m from Gajulamandyam, Tirupati District, Andhra Pradesh, India to avoid surface organic matter and disturbances. The collected soil was air-dried and gently pulverized and passed through a 4.75 mm sieve to ensure uniform particle size before laboratory testing. The soil exhibited typical characteristics of expansive soils, including high plasticity and low strength, making it unsuitable for construction without stabilization. All tests were carried out following the relevant Indian Standard (I.S) codes.

Table 1: Properties of Tested Soil

S No	Property		Value
			Soil
1	Grain size Analysis		
a	Gravel (%)		1.00
b	Sand (%)		43.00
c	Silt (%)		41.80
d	Clay (%)		14.20
2	Atterberg limits		
a	Specific Gravity (G)		2.68
b	Liquid Limit (%)		74.0
c	Plastic Limit (%)		15.1
d	Plasticity Index		58.9
3	Free Swell Index (%)		235.0
4	Degree of Saturation		Very High
5	Optimum Moisture Content (OMC) (%)		14.8
6	Unconfined Compression Strength (kPa)		148.84
7	California Bearing Ratio (%)	Unsoaked	4.56
		Soaked	2.74
8	IS Classification		CH (Clay with high Plasticity)

2.1.2 RICE HUSK BIOCHAR (RHB)

Rice Husk Biochar (RHB) used in this study was procured from Prithvi Chemical Manufacturing Company, Tumkur District, Karnataka. The Rice Husk Biochar was produced through controlled pyrolysis of Rice Husk and used as a soil stabilizing agent. The chemical composition of RHB was determined using Energy Dispersive X-ray Analysis (EDAX), and the test report was provided by PSG Tech, Coimbatore District, Tamil Nadu.

Table 2: Chemical Composition (EDAX) of Rice Husk Biochar (PSG Tech, Coimbatore, Tamil Nadu)

Element	Element wt.%	Oxide Form	Factor	Calculated Oxide wt.%
Si	45.42	SiO_2	2.139	97.17
K	2.35	K_2O	1.204	2.83
Total				100.00

2.1.3 MICROBES

The bacteria Bacillus Subtilis was used in this study for Microbially Induced Calcite Precipitation (MICP). The strain was isolated from a soil sample collected from the Lanco industry pond located at Rachagunneru near Tirupati. The identified bacterial strain belongs to the family Bacillus subtilis (C4nc8) and is characterized by a rod-shaped morphology and Gram-positive nature. The strain is registered with a GenBank accession number OP363349, and the strain name is designated as LSRCE. The bacterial culture required for MICP treatment was prepared in the Bioremediation Laboratory of the Geotechnical Division, Department of Civil Engineering, SVUCE, following standard microbial culturing and serial dilution procedures to ensure adequate bacterial growth and activity.

Bacterial Culture Preparation

The bacterial culture was prepared through standard microbiological procedures, beginning with the collection of soil samples, which were air-dried for two days and pulverized into fine powder. A preheated sample (below 50 °C) was subjected to serial dilution using sterile distilled water in a sequence of test tubes (10^{-1} to 10^{-7}). Nutrient agar medium was prepared by mixing agar (20 g/L) and nutrient broth (13 g/L) with distilled water, followed by autoclaving and pouring into sterile Petri dishes for solidification. Diluted samples were inoculated onto the agar plates using a sterile L-rod and incubated under controlled conditions for 24 hours to allow colony formation. Gram staining was then performed using crystal violet, iodine, decolourizer, and safranin to identify bacterial characteristics, confirming Gram-positive rod-shaped bacteria. Selected colonies were further isolated using quadrant streaking techniques and incubated again to obtain pure bacterial cultures.

Bio-stimulation and MICP Treatment Process

Here Bio-Stimulation was adopted to enhance the activity of indigenous bacteria for Microbially Induced Calcite Precipitation (MICP). The enrichment solution was prepared using 100 mM Sodium Acetate, 333 mM Urea, and Nutrient Broth (13 g/L), while the cementation solution consisted of 250 mM Calcium Chloride. These solutions were added to stimulate bacterial activity and promote calcite precipitation within the soil matrix. The bacterial solution was mixed with soil at its Optimum Moisture Content (OMC), with 1 ml of bacterial culture per 1000 ml of water. Laboratory tests were conducted on both untreated and bio-stimulated soil samples to evaluate changes in plasticity characteristics, strength, swelling behaviour, and chemical properties.

2.2 Methodology Adopted

The methodology adopted in this study follows a systematic experimental approach to evaluate the effectiveness of Rice Husk Biochar (RHB) and Microbially Induced Calcite Precipitation (MICP) in stabilizing expansive clayey soil. Initially, the soil was collected, air-dried, pulverized, and tested to determine its index and engineering properties. RHB was then added to the selected expansive soil in varying proportions (0%, 5%, 10%, and 15%), while MICP treatment was applied using different dosages (0 ml, 2 ml, 4 ml, 6 ml, and 8 ml) through bio-stimulation techniques. Based on the experimental results, optimum values for both RHB and MICP were identified individually. All samples were prepared at Optimum Moisture Content (OMC) and subjected to laboratory tests including Plasticity Characteristics, Compaction, Unconfined Compressive Strength (UCC), and California Bearing Ratio (CBR). The results were analysed to compare the performance of individual treatments and the combined optimum mix for determining the most effective stabilization approach.

3. RESULTS AND DISCUSSION

The laboratory tests were conducted to evaluate the effectiveness of Rice Husk Biochar (RHB) and Microbially Induced Calcite Precipitation (MICP) in improving the engineering properties of expansive soil. Tests such as Atterberg limits, compaction, Unconfined Compressive Strength (UCC), and California Bearing Ratio (CBR) were carried out on untreated and treated soil samples. The results obtained are discussed below.

3.1 Plasticity Characteristics

Plasticity characteristics indicate the consistency and swelling behaviour of expansive soil. Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) tests were conducted on untreated soil and treated soil with different percentages of RHB and MICP.

Table 3: Plasticity Characteristics of (Soil - RHB) Mixes

Description	Liquid Limit (LL) (%)	Plastic Limit (PL) (%)	Plasticity Index (PI) (%)
Soil	74.0	15.1	58.9
Soil + 5% RHB	70.0	21.5	48.5
Soil + 10% RHB	79.0	24.8	54.2
Soil + 15% RHB	90.0	25.7	65.3

Table 4: Plasticity Characteristics of (Soil - MICP) Mixes

Description	Liquid Limit (LL) (%)	Plastic Limit (PL) (%)	Plasticity Index (PI)
Soil	74.0	15.1	58.9
Soil + 2 ml MICP	35.0	14.4	20.6
Soil + 4 ml MICP	31.0	15.7	15.4
Soil + 6 ml MICP	33.0	17.1	15.2
Soil + 8 ml MICP	33.0	17.5	15.4

3.1.1 Liquid Limit (Soil – RHB, Soil – MICP)

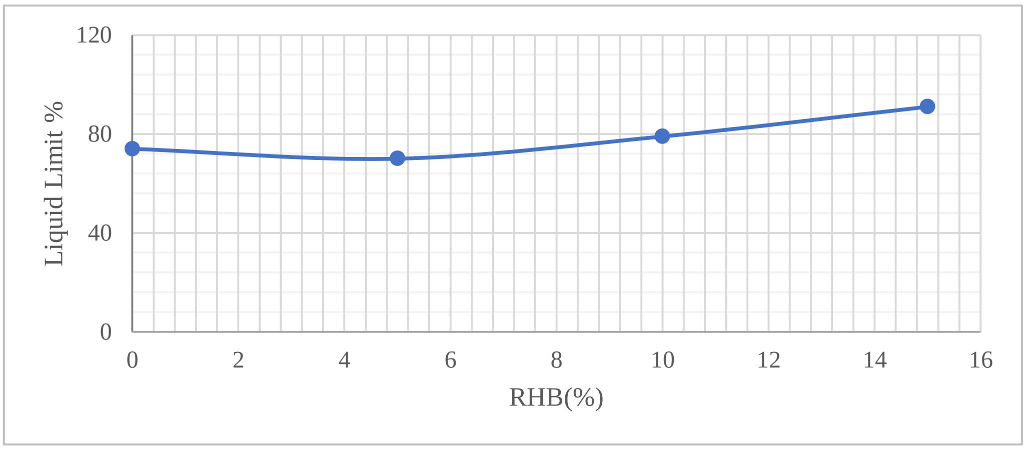

Fig.1: Variation of Liquid Limit of (Soil – RHB) Mixes

3.1.2 Plastic Limit (Soil – RHB, Soil – MICP)

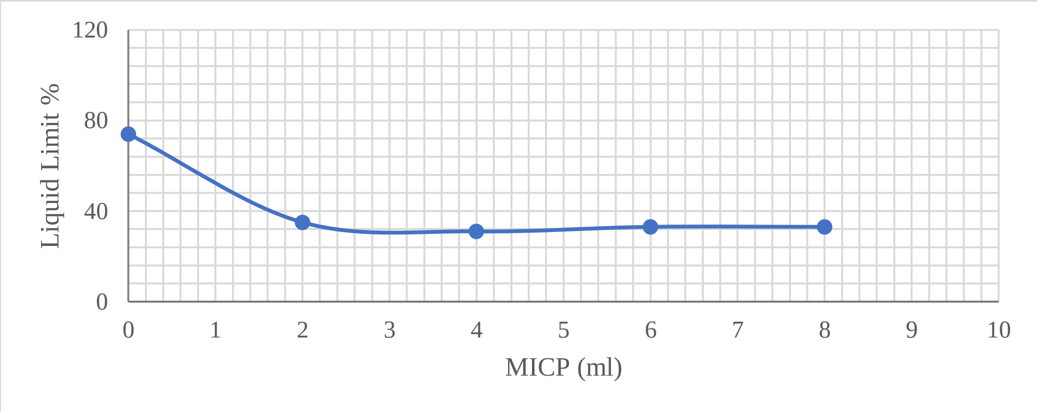

Fig.2: Variation of Liquid Limit of (Soil – MICP) Mixes

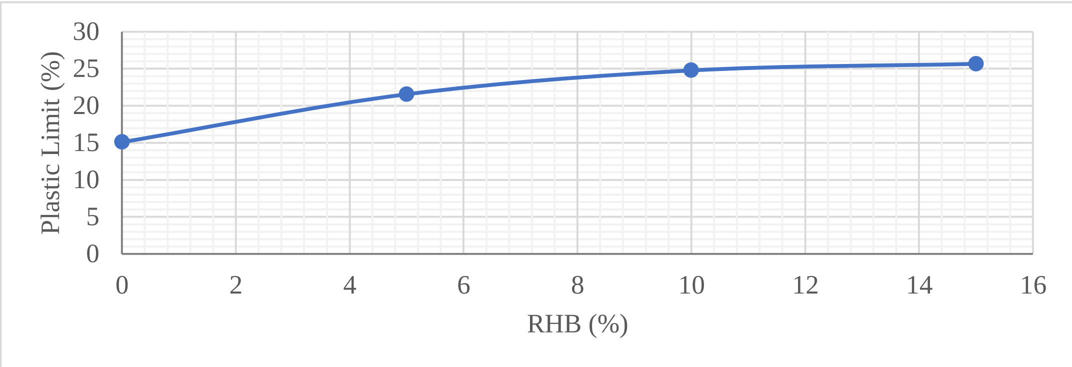

Fig.3: Variation of Plastic Limit of (Soil – RHB) Mixes

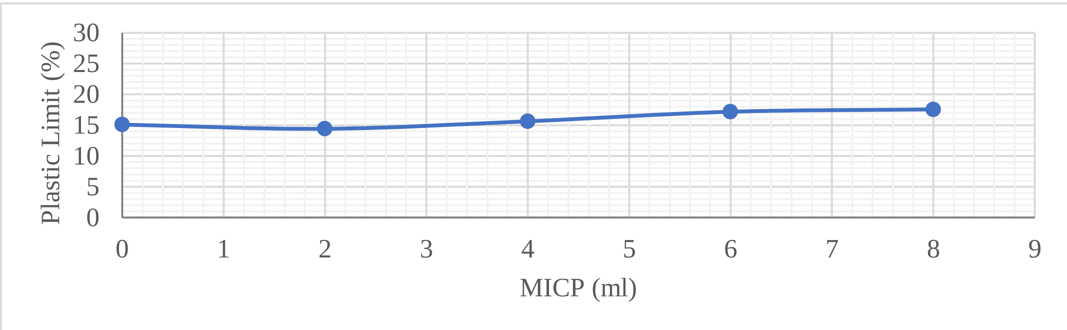

Fig.4: Variation of Plastic Limit of (Soil – MICP) Mixes

In RHB amended soil, the plastic limit shows an increasing trend with higher biochar content. This behaviour is mainly due to the water absorption capacity of RHB, which reduces the effective moisture available for clay interaction and decreases clay activity. As a result, a higher water content is required for the soil to reach the plastic state.

For MICP treated soil, the plastic limit initially exhibits a slight decrease, which can be attributed to the presence of treatment solution adding temporary moisture. With an increase in treatment level, the plastic limit gradually increases due to calcium carbonate ($CaCO_3$) precipitation, which enhances particle bonding and modifies soil structure. This leads to improved workability and requires relatively higher water content to attain the plastic state.

3.2 Compaction Characteristics

Compaction characteristics indicate the moisture–density relationship and compaction behaviour of expansive soil. Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) tests were conducted on untreated soil and soil treated with different percentages of RHB and different dosages of MICP to evaluate their influence on the compaction properties of soil.

3.2.1 Soil – RHB Mixes:

Table 5: Compaction Characteristics Soil – RHB Mixes

RHB (%)	OMC (%)	MDD (kN/m³)
0	14.8	16.97
5	17.7	16.19
10	23.3	15.30
15	23.8	14.82

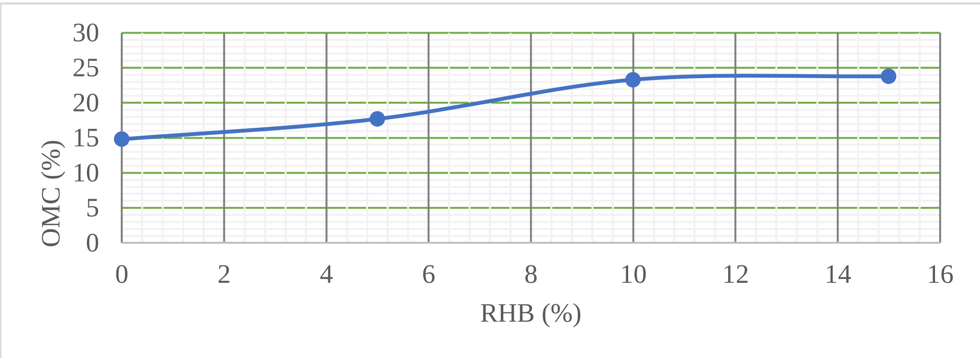

Fig.5: Variation of OMC of (Soil – RHB) Mixes

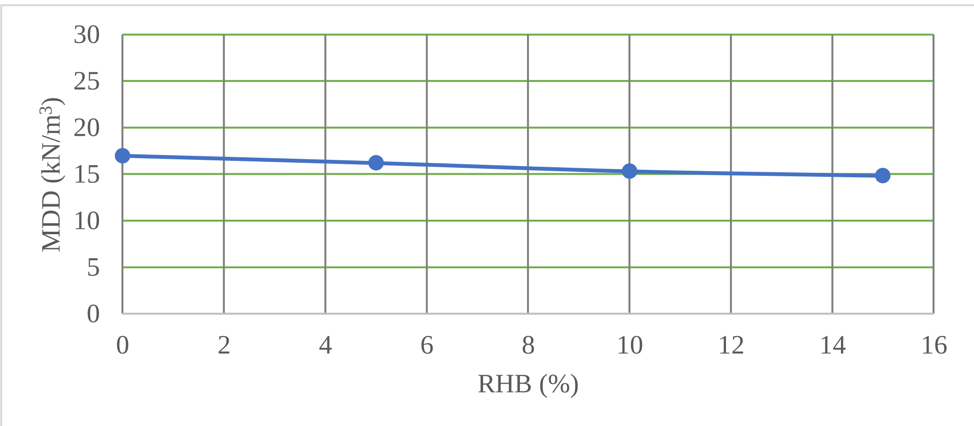

Fig.6: Variation of MDD of (Soil – RHB) Mixes

3.2.2 Soil – MICP Mixes:

Table 6: Compaction Characteristics Soil – MICP Mixes

MICP (ml)	OMC (%)	MDD (kN/m³)
0	14.8	16.97
2	13.8	17.86
4	12.2	18.06
6	13.5	18.06
8	14.8	17.86

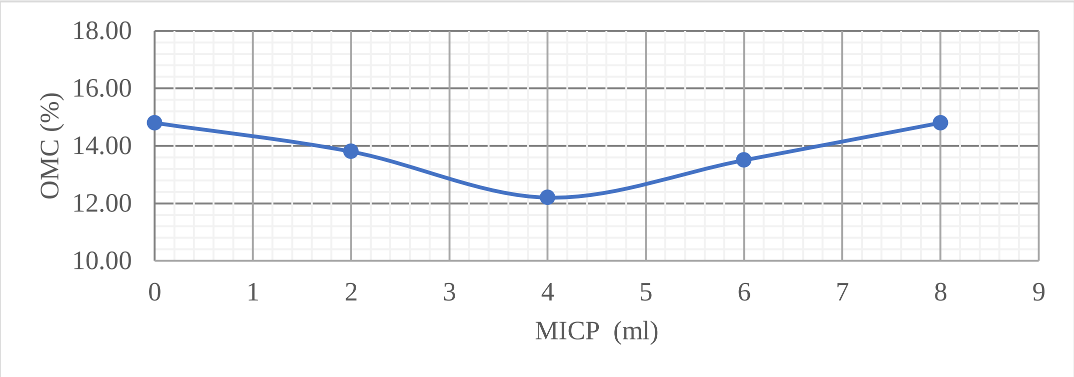

Fig.7: Variation of OMC for Soil–MICP Mixes

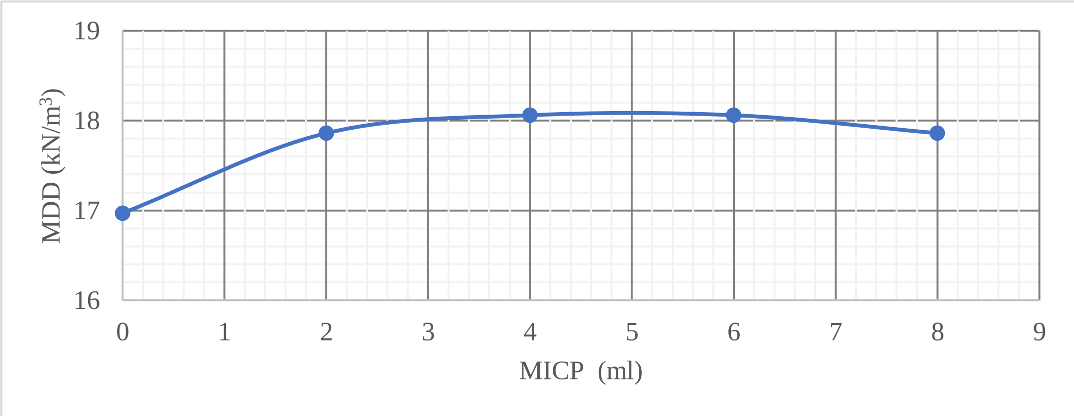

Fig.8: Variation of MDD for Soil–MICP Mixes

3.3 Unconfined Compressive Strength (UCC):

The Unconfined Compressive Strength (UCC) test was conducted on untreated soil, (Soil– RHB), and (Soil– RHB). The test was performed to determine the compressive strength of the soil samples under axial loading conditions. The test was carried out on untreated soil, which exhibited an Unconfined Compressive Strength of 148.85 kPa. All samples were prepared at the respective Optimum Moisture Content and tested curing under a strain-controlled conditions.

3.3.1 UCC of (Soil – RHB) Mixes

Table 7: UCC of (Soil – RHB) Mixes

UCC (kN/m²)				
S.No	Curing Period (days)	Soil + 5% RHB	Soil + 10% RHB	Soil + 15%RHB
1	0	218.10	184.60	180.90
2	3	572.16	570.00	189.05
3	7	300.81	265.42	264.37

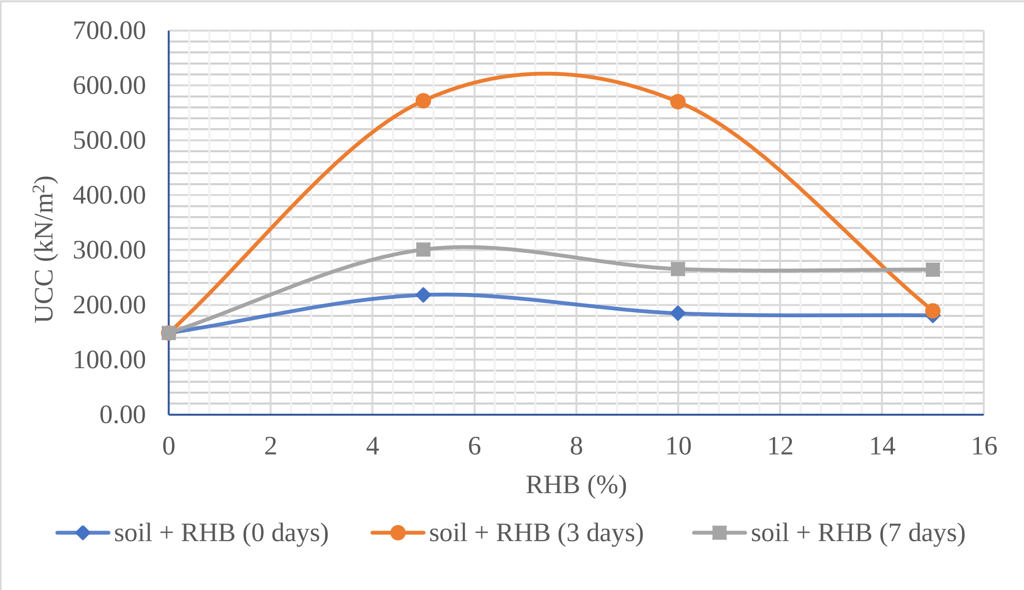

Fig.9: Variation of UCC for (Soil – RHB) Mixes with Curing Period (days)

3.3.2 UCC of (Soil – MICP) Mixes

Table 8: UCC of (Soil – MICP) Mixes

UCC (kN/m²)					
S.No	Curing Period (days)	Soil + 2 ml MICP	Soil + 4 ml MICP	Soil + 6 ml MICP	Soil + 8 ml MICP
1	0	252.52	452.44	419.10	332.02
2	3	275.00	474.65	425.00	424.25
3	7	303.97	526.06	470.60	465.57

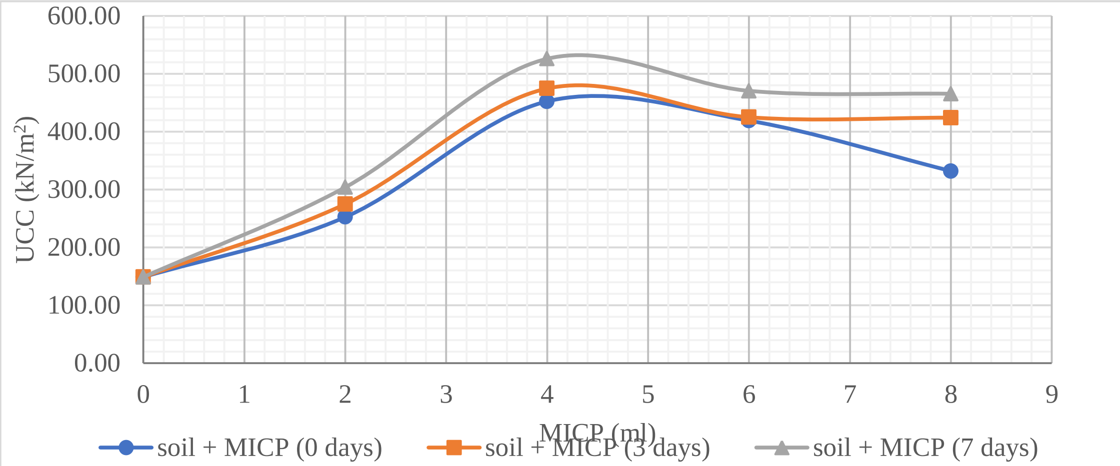

Fig.10: Variation of UCC for (Soil – MICP) Mixes with Curing Period (Days)

3.4 California Bearing Ratio

In Unsoaked and Soaked CBR tests were conducted on soil with Optimum admixtures (RHB) and (MICP) at different curing period (days).

3.4.1 Unsoaked CBR

Table 9: Unsoaked CBR values of (Soil – RHB) mixes and (Soil – RHB) mixes at optimum content with curing period (days)

S.No	Curing Period (days)	CBR (%)	
		soil + 5% RHB	Soil +4ml MICP
1	0	11.9	15.5
2	3	13.7	20.9
3	7	12.8	21.9

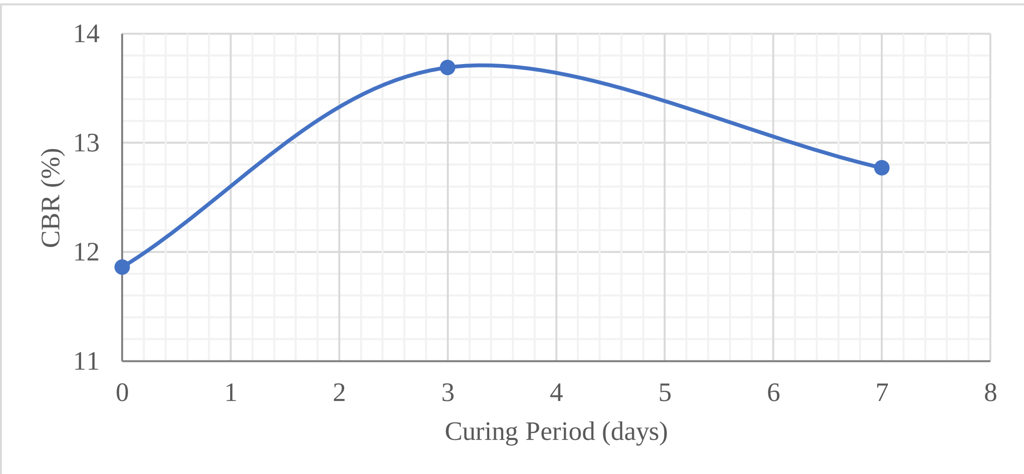

Fig.11: Variation of Unsoaked CBR of (Soil – 5% RHB) mixes with curing

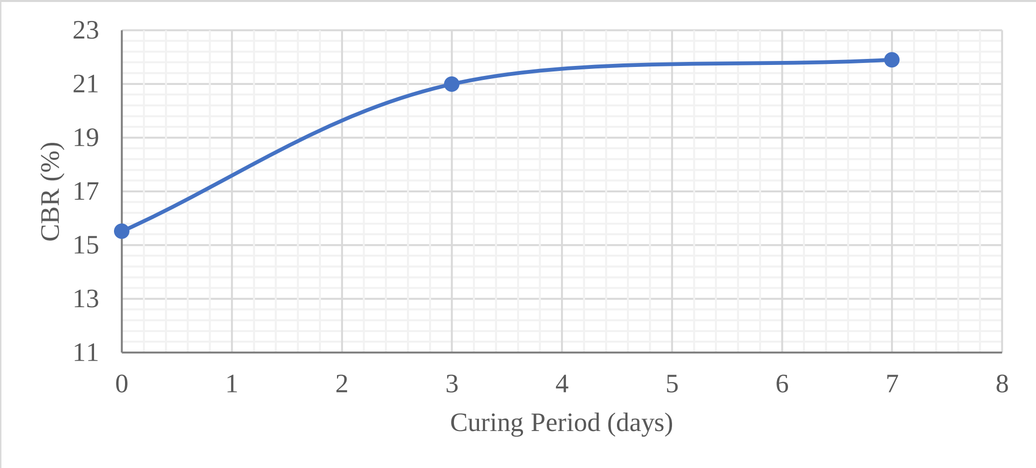

Fig.12: Variation of Unsoaked CBR of (Soil – 4ml MICP) mixes with curing

3.4.2 Soaked CBR

Table 10: Soaked CBR values of (Soil – RHB) mixes and (Soil – RHB) mixes at optimum content with curing period (days)

S.No	Curing Period (days)	CBR (%)	
		Soil + 5% RHB	Soil +4ml MICP
1	0	9.1	14.6
2	3	10.9	18.3
3	7	10.0	19.2

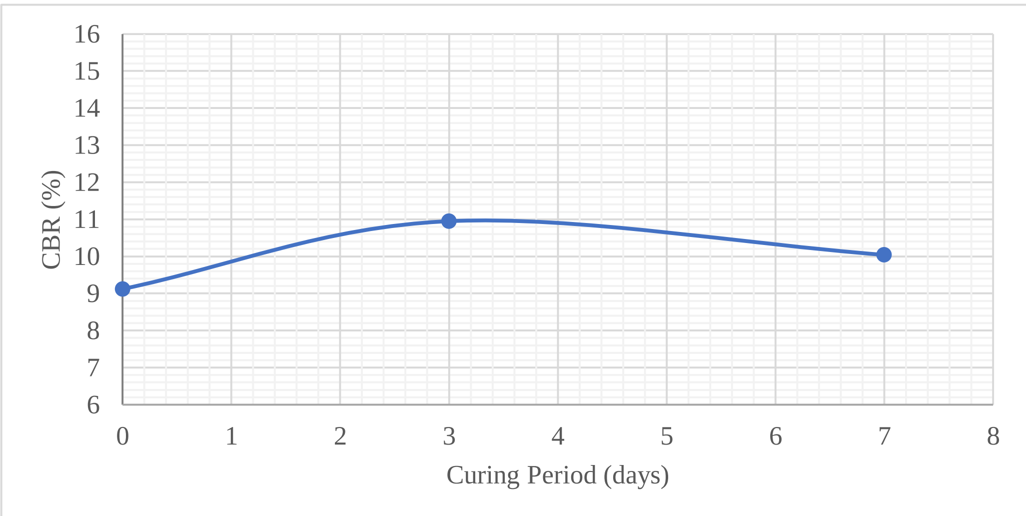

Fig.13: Variation of Soaked CBR of (Soil – 5% RHB) mixes with curing

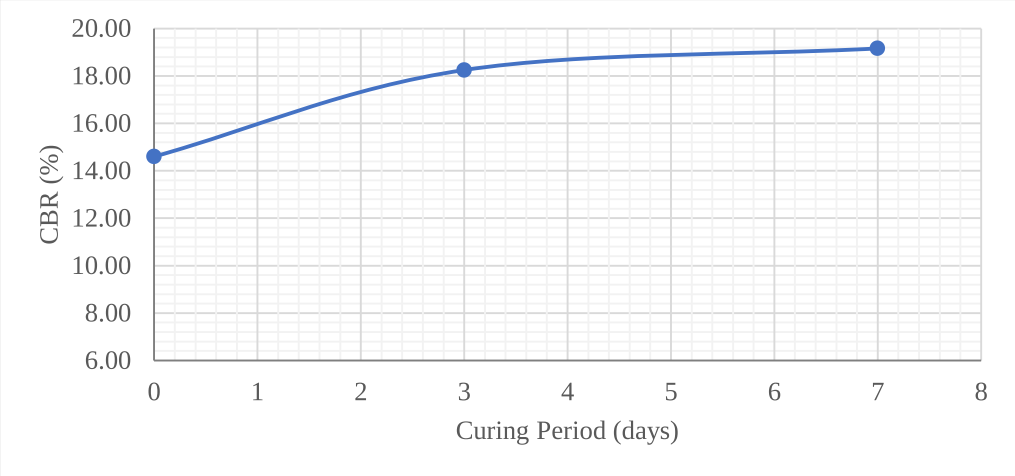

Fig.14: Variation of Soaked CBR of (Soil – 4ml MICP) mixes with curing

RHB treated soil showed an increase in Optimum Moisture Content (OMC) and a decrease in Maximum Dry Density (MDD) with increasing biochar content due to its porous and lightweight nature. The Unconfined Compressive Strength (UCC) increased up to the optimum RHB content and then decreased at higher percentages. Maximum strength was observed at 3 days curing due to improved bonding and partial pozzolanic reactions. The soaked CBR value of the Soil–5% RHB mix increased from 9.1% at 0 days to 10.9% at 3 days and slightly decreased to 10.0% at 7 days due to moisture redistribution and limited bonding effect.

MICP treated soil initially showed a decrease in OMC followed by a gradual increase at higher treatment levels, while MDD increased up to the optimum dosage due to calcium carbonate ($CaCO_3$) precipitation and particle bonding. The UCC increased significantly with curing period, with maximum strength observed at 7 days due to continuous calcite formation and densification of the soil matrix. The soaked CBR value of the Soil–4 ml MICP mix increased continuously from 14.6% at 0 days to 18.3% at 3 days and 19.2% at 7 days, indicating improved load-bearing capacity and better performance compared to RHB treated soil.

4. CONCLUSIONS:

Experimental studies were conducted on effectiveness of RHB and MICP in stabilising an local expansive soil. Based on the test results the following conclusions are made:

1. The liquid limit decreased from 74.0% to 70.0% at 5% RHB and increased to 90.0% at 15% RHB.
2. The plastic limit increased from 15.1% to 25.7% with increase in RHB content.
3. The optimum moisture content increased from 14.8% to 23.8%, while the maximum dry density decreased from 16.97 kN/m^3 to 14.82 kN/m^3 with increase in RHB content.
4. The Unconfined Compressive Strength (UCC) increased from 148.85 kN/m^2 to 572.16 kN/m^2 at optimum RHB content (5% @ 3 days), which is approximately 3.84 times the untreated soil.
5. The California Bearing Ratio (CBR) increased from 4.56% to 13.7%, which is approximately 3 times the untreated soil.
6. The liquid limit decreased from 74.0% to 31.0% and remained nearly constant at higher treatment levels due to reduced clay activity.
7. The plastic limit initially decreased from 15.1% to 14.4% and then increased to 17.5% with increase in treatment level.
8. The optimum moisture content decreased from 14.8% to 12.2% and then increased to 14.8%, while the maximum dry density increased from 16.97 kN/m^3 to 18.06 kN/m^3 at optimum treatment.
9. The Unconfined Compressive Strength (UCC) increases from 148.85 kN/m^2 to 526.06 kN/m^2 at optimum MICP content (4 ml @ 7 days), which is approximately 3.53 times the untreated soil.
10. The California Bearing Ratio (CBR) increased from 4.56% to 21.9%, which is approximately 4.80 times the untreated soil.
11. Among the two admixtures, RHB and MICP, MICP was found to be more effective than RHB in improving the strength characteristics of soil based on UCC and CBR results.

12. Both RHB and MICP are sustainable materials that support the Go Green concept by promoting eco-friendly soil stabilisation and contributing to environmental protection and natural sustainability.

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