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Evaluation of Geotechnical Properties and Microstructure Analysis Lime Blended Black Cotton Soil

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ABSTRACT: Black cotton soil, show evidence of excessive amount of swell accompanied by reduction of shear strength and shrinkage with moisture contents forms cracks. A study carried out to understand the influence of hydrated lime to mitigate the weak properties of black cotton soil. Quantities of lime blend 2, 4, 6, 8 and 10% of dry soil content. Experimental studies have been conducted to assess the consequences on plasticity, swelling, compaction, unconfined compressive strength tests conducted for 1, 3, 7 and 28 days of curing and California bearing ratio tests performed on 4 days of soaked condition samples. Analytical techniques used to detect at the microscopic level changes that occurs in stabilized sample as compare to untreated soil by scanning electron micrograph (SEM) and energy dispersive spectroscopy (EDS). Test results show that there is a decrease in plasticity and swelling behavior and raising the unconfined compressive strength and a **substantial improvement in the CBR value. Microscopic examination by SEM and EDS analysis of the blended sample shows the advancement of reaction product patches and the formation of cementitious compound peaks. Attributes in chemical and sample structures also been seen. The results show that hydrated lime is effective in improving the weak properties of black cotton soil.**

Keywords: Black cotton soil, California bearing ratio, Compaction, Energy Dispersive Spectroscopy, Hydrated lime, Scanning Electron Microscopy, Swelling and Unconfined compressive Strength.

Abbreviations: CBR, California bearing ratio; EDS, Energy Dispersive Spectroscopy; IS, Indian Standard; SEM, Scanning Electron Microscopy; UCS, Unconfined compressive Strength.

I. INTRODUCTION

Black cotton soil is one of the world's expansive soils of gray to black colour. Black cotton soils in India are classed as expansive soils due to montmorrilonite minerals [1]. The reform in volume to a great extent due to the presence or lack of water content seems to have a large swelling pressure on the structure [2]. BC soil does not have suitable geotechnical properties to be used as a pavement and base layer as a building material. Owing to high plasticity, infrastructure are cracked and broken up. Structures built on expansive soil undergo serious damage. Destruction of infrastructure projects on imposes a high cost burden. Special attention is needed to the failure of constructions on problematic soil [3]. Replacing expansive soil with non expansive material and transporting from longer distances tends to cause environmental damage and uneconomic. Stabilization of soil is more beneficial and environmentally sustainable while used for building purposes [4]. Improving the soil properties of low bearing capacity will lead to the construction economy. Stabilization of expansive soil with various additives has been one of the promising techniques for tackle the problematic behavior. Stabilization is the method of enhancing the soil's properties by adjusting its gradation, strengthens the linkages between granules and decreases soil expansibility and contractility. Expansive soil has a more specific surface area and cation exchange potential due to the content of clay. Chemical composition of materials implies effectiveness in soil stabilization [5]. When the lime is dissolved in clay soil, the transition occurs as the calcium cations of the lime replace the cations present on the surface of the clay mineral, facilitated by the high p^H of the lime water system. The first stage of the chemical reaction involves immediate changes in soil texture and properties induced by cation exchange. Free calcium interacts with the adsorbed clay mineral cations, resulting in a decrease in the size of the diffused water film adjacent to the clay particles. The reducing of the diffused water film makes it possible for the clay particles to come into closer contact with each other, inducing flocculation or agglomeration of the clay particles that turn the plate like particles towards a needle like silt material. As lime is introduced to the soil, the reaction of silica or alumina of soil induces the formation of calcium silicate and aluminates hydrates as a cementitious compound. As many previous researchers identified the behavior of stabilized soil with performing mechanical tests and very little literature is available regarding identification of changes that occurs in micro pores, structures of soil mass and chemical attributes by micro structure analyses with the help of a Microscopic examination by SEM and EDS analysis.

II. BACKGROUND OF STUDY

Stabilization of expansive soil using various binders such as Portland cement and cement Kiln dust, fly ash fly ash and slag by various researchers. As better technological advancements and a concern for the depletion of non-renewable resources, the enhancement of soil properties using chemical additives has now become increasingly popular. Lime offers a cost-effective, easy-to-use and viable approach for Soil improvement. The benefits of lime stabilization are substantial improvements in soil properties, increase in strength over time, speedily boost load capacity, decrease in volume changes, stability and, most importantly, more economical compare to other stabilizing agents. A variety of research studies have shown the usefulness effect of soil performance against behavioral decreases in volume change. Use of coir fiber for strengthens pavement shoulder sub grade [6]. Use of coal bottom ash in concrete to identified the behavior of concrete by non destructive test and microstructure analysis [7]. Owing to the incorporation of the lime swelling potential the structural damage is minimized to a considerable extent [6], the strength ability is similarly improved [7]. Lime is commonly used to enhance the strengthening of the construction site. CBR values improve with an increase in lime [8]. Lime stabilizer for road pavement sub grade as per AASHTO 2004 was evaluated [9]. The soil lime blend improves the cohesion and friction angle responsible for enhancing compressive strength [10]. Lime stabilization is a complex phenomenon and the factors responsible are clay minerals, soil type, lime percentage and curing time, which require attention during the examination [11]. It has been observed from literature review that most published work presented only geotechnical lab test to identify the behavior of blended samples and very few observed at microscopic level investigations through SEM and EDS analysis, hence attempt have been made in this work to showcase the attributes in micro -pores and chemical compounds.

III. MATERIALS AND METHODS

Black cotton soil extracted from Khadakwasala Pune, Maharashtra State of India. After scraping the top overburdened soil at a depth of one meter, then the sample collected. Black cotton soil was first pulverized and then dried in the oven to conduct a sieve analysis as per IS 2720 (Part IV) 1985.

Hydrated lime import from industry having a whitish crystal nature of particle sizes less than 75 microns in dry powder form and a calcium hydroxide content of more than 96 %.

Fig. 1. Soil collection pit.

Fig. 2. Hydrated lime.

Tests conducted to determine the basic properties of soil and hydrated lime blended soil include gradation, pH value of blend samples, liquid, plastic and shrinkage limits, Standard proctor test, Unconfined compression test, California bearing ratio, Differential free swell test, Scanning Electron Microscopy (SEM) analysis, Energy Dispersive Spectroscopy (EDS).

According to IS 2720, (Part 26)1987, the pH value of the blended samples was calculated as per IS 2720 (Part 1)1983, two buffer solutions of p^H 4 and 9.2 at 25^oC were used to conduct the test and the pH meter was calibrated. 30 gm of sample and 75 ml of water suspension are stirred in a 100 ml beaker and allow stand for one hour. The liquid limit Analysis was conducted using the liquid limit Device of Cassgrande in compliance with IS 2720 (Part V) 1985. As per IS 2720 (Part V) 1985, the plastic limit examination was carried out. According to IS 2720 (Part VI) 1972, shrinkage limit Analysis has been performed. Under Standard Proctor Test IS 2720 (Part VII) 1980, soil compaction behavior observed to determine the relationship between moisture content and soil density. Unconfined compressive strength tests conducted to assess the strength activity as per IS 2720 (part 10) 1973. The CBR test was carried out in compliance with IS 2720 (Part 16) 1987. The soil was compacted in the mould by light compaction and compacted in 3 equal layers and each layer received 55 blows of 2.6 kg rammer. In order to assess the swelling activity, the free swell test carried out in compliance with IS 2720 (Part III) 1980. Analytical techniques used to recognize samples at the microscopic level by scanning electron micrograph (SEM) and energy dispersive spectroscopy (EDS) of soil, hydrated lime and lime blended samples observed by Nova NanoSEM 450 for SEM and EDS analysis with the help of Bruker Xflash 6130 model. Pieces of soil samples from UCS post test specimens were dried which is used for examination.

IV. RESULTS AND DISCUSSION

The results of the sieve analysis and as per the IS classification, the soil classified as CH. Behavior of lime blended samples on geotechnical properties stated below.

A. pH value

Various researchers [12-14] explored the quantity of lime needed and its optimum content to meet the need to enhance the soil properties. The amount of lime needed for stabilization ranges from 3 to 10% depending on the soil type [12]. Results obtained by pH meter of soil mixture are shown in Table 1 for hydrated lime.

Table 1: pH value of blended sample.

S. No.	1	2	3	4	5	6
Lime %	0	2	4	6	8	10
P^H value	6.7	8.9	10.2	11.4	11.4	11.4

As shown in Table 1 addition of lime from 2, 4, 6, 8 and 10% the alkaline nature of soil sample increases from 6.7 of untreated soil to 8.9, 10.2, 11.4, 11.4 and 11.4 respectively. Maximum pH value obtained for 6% of lime indicates that the optimum lime content and beyond that it remains constant.

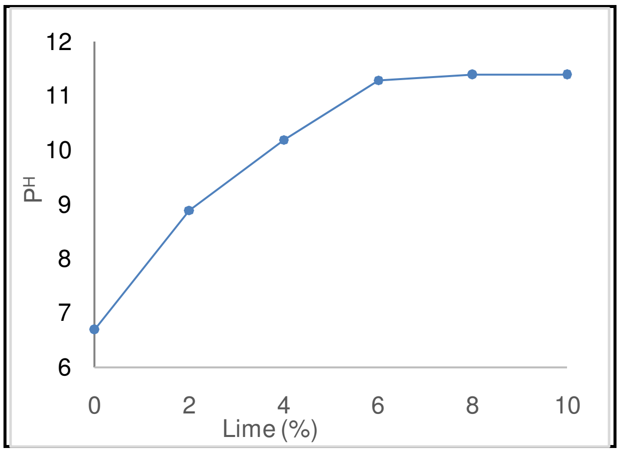

Fig. 3. pH value with % of hydrated lime.

The high alkaline atmosphere (pH at 11 to 12) is needed for the Pozzolanic reaction, which is accomplished by adding an optimum amount of lime. As shown in Fig. 3, the PH test indicates that the optimum hydrated lime content is 6%.

B. Effects on consistency limit

From the test carried out, the liquid limit percentage of the untreated soil sample found 69 and the pattern of decreasing observed as the lime content raised the liquid limit of the treated soil by a decrease of 61.5 for 10 % of hydrated lime. Test results show that the plastic limit value of the soil rising with the addition of the hydrated lime percentage. Results show that the shrinkage limit percentage of 20.83 of natural soil decreased to 8.33 for 10 % of hydrated lime. Variation of the consistency limit value for 0 to 10% of hydrated lime is shown in Fig. 4.

The soil behavior due to the presence of water is indicated by the plasticity index, observed to decrease with the application of lime in black cotton soil, rendering the soil more workable. Plasticity Index percentage value decreased from 24.13 to 4.07. This happens because the hydrated lime reduces the thickness of the diffuse double coating adjoining to the clay particle.

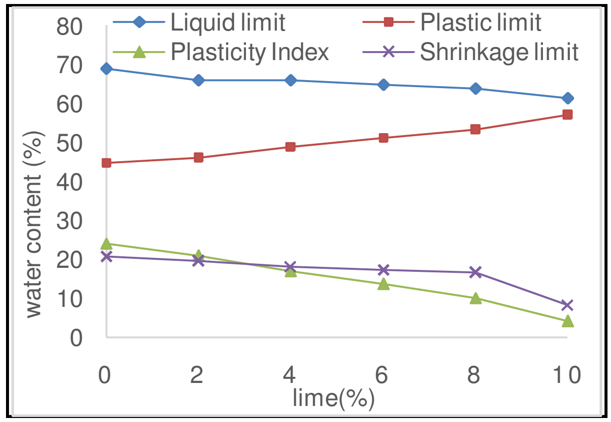

Fig. 4. Variation of consistency index.

C. Compaction characteristics

It has been observed from the compaction test that, compared to untreated soil, the MDD values decreased from 13.46 to 12.81 kN / m^3 and the OMC percentage values increased from 31.05 to 38.33 by hydrated lime addition from 0 to 10 % The reduction in the MDD is due to the formation of voids and the opening of the arrangement.

D. Unconfined compressive strength

Testing results of unconfined compressive strength as shown in Fig. 5 demonstrates that as the amount of lime increases, the strength of the stabilized soil increases for all curing periods. The strength of 10% hydrated lime after the 28 day curing period is 0.65 N / mm^2 compared to 0.25 N / mm^2 of untreated soil. The cementation process is primarily responsible for pozzolanic reaction products due to calcium silicate hydrates (CSH) and calcium alumina hydrates (CAH) to boost the strength and stiffness of the blend soil mixture by decreasing pores.

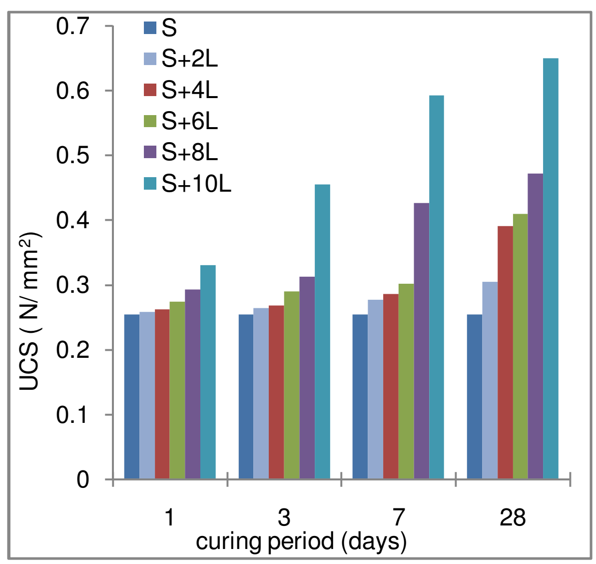

Fig. 5. Variation of UCS value with curing pariod.

E. Effects on California bearing ratio

As shown in Fig.8, the load penetration curve of the CBR test is shown for samples tested of different proportion mix. The CBR value of 4 days soaked samples found to be 1.57 and 1.98, 2.57, 3.10, 4.43 and 5.29, respectively, for 2, 4, 6, 8 and 10 % of hydrated lime. Experimental analysis shows a substantial improvement in the CBR value with an increase in the hydrated lime amount.

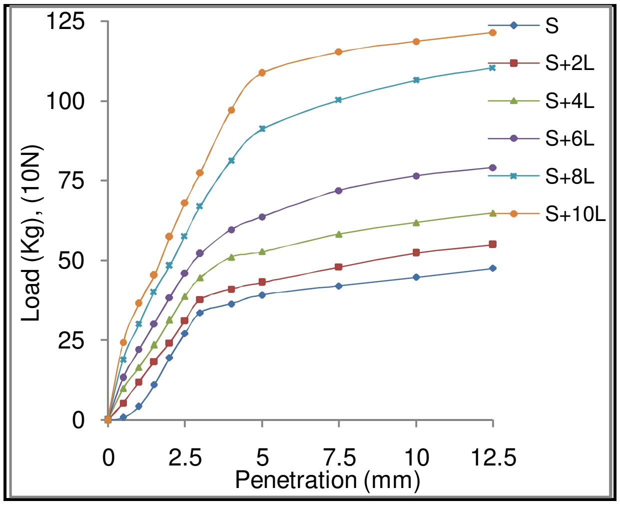

Fig. 6. Load penetration curve of CBR test.

F. Swelling characteristics

The expansive nature of the soil has calculated the ability of the soil to swell by the free swell index.

Table 2: Free swell index.

S. No.	1	2	3	4	5	6
Lime %	0	2	4	6	8	10
Free swell (%)	80	62	50	45	39	33

From the test results as shown in Table 2, it can be observed that the addition of hydrated lime significantly reduces its swelling behavior of soil.

Analytical techniques used to detect at the microscopic level by Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) for samples as shown below.

G. Scanning Electron Microscopy (SEM)

Black cotton soil sample, lime and blended sample of 6% lime of the 28 day curing period were analyzed. FEM photographs are included in the figures.

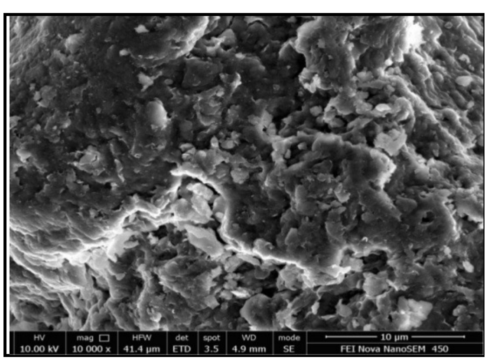

Fig. 7. FESEM image of black cotton soil sample.

The SEM picture as shown in Fig. 7 of the natural soil sample indicates the presence of flaked particles and voids.

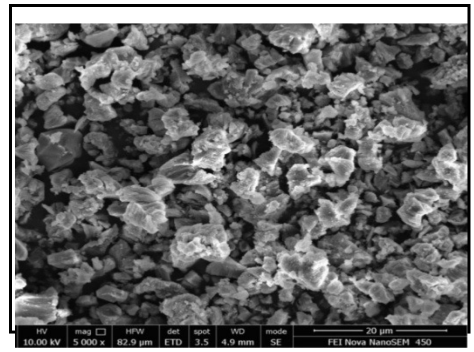

Fig. 8. FESEM image of hydrated lime.

Lime samples shows quartz-sized angular grain morphology, contained with fine calcite grains.

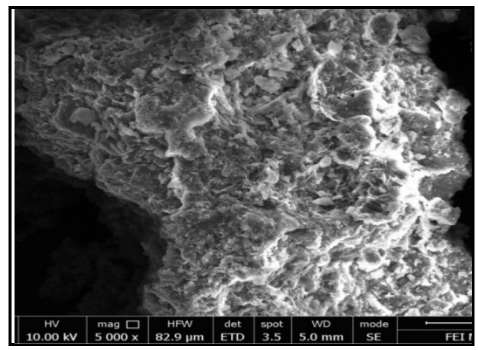

Fig. 9. FESEM image of 6% lime blend soil sample.

SEM micrograph as shown in Fig. 9 at 6% lime of 28 days curing period reveals that the flaked grains vanish and a uniform grain configuration can be seen, the micrograph demonstrates well developed reinforced crystalline structures in reticulated and flocculated format that allow the soil to bear a high pressure

H. Energy Dispersive Spectroscopy (EDS)

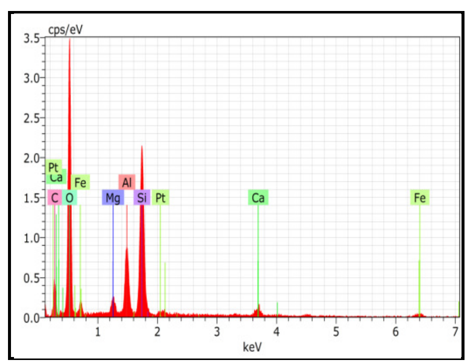

Fig. 10. EDS Spectrum of Black cotton soil.

Table 3: Elements in soil sample.

El	AN	unn. [wt.%]	C norm. [wt.%]	C Atom. [at.%]	C Error [wt.%]
O	8	44.25	44.17	54.55	6.40
Si	14	25.99	25.94	18.25	1.16
C	6	9.92	9.90	16.29	2.39
Fe	26	8.92	8.91	3.15	0.82
Al	13	7.39	7.38	5.40	0.41
Ca	20	2.05	2.05	1.01	0.16
Mg	12	1.65	1.65	1.34	0.15
		100.19	100.00	100.00	

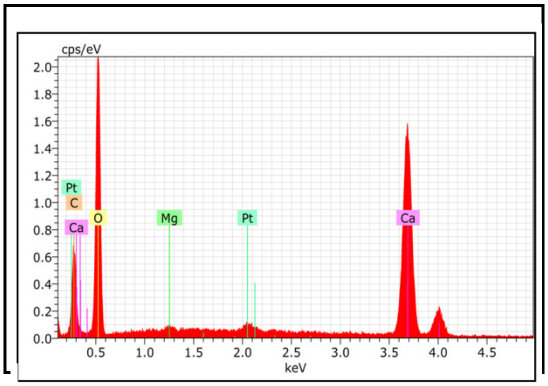

Fig. 11. EDS Spectrum of hydrated lime.

Table 4: Elements in hydrated lime.

A	AN	unn. [wt.%]	C norm. [wt.%]	C Atom. [at.%]	C Error [wt.%]
Ca	20	48.21	49.20	27.17	1.67
O	8	43.84	44.74	61.90	5.87
C	6	5.69	5.80	10.69	0.98
Mg	12	0.26	0.26	0.24	0.05
		98.00	100.00	100.00	

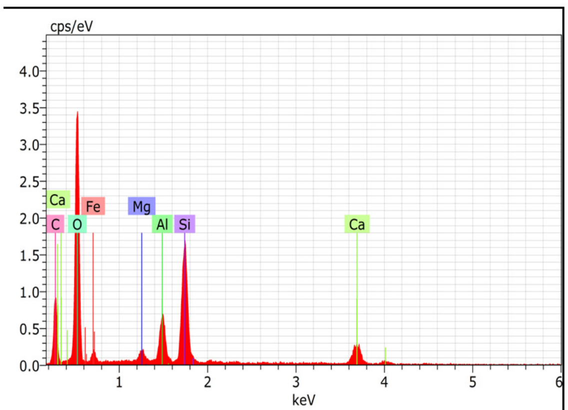

Fig. 12. EDS Spectrum of 6% lime blended soil sample.

Table 5: Elements in 6% lime blended soil sample.

El	AN	unn. [wt.%]	C norm. [wt.%]	C Atom. [at.%]	C Error [wt.%]
O	8	45.46	46.96	54.24	6.16
Si	14	17.86	18.01	11.85	0.79
C	6	15.68	15.81	24.33	2.66
Fe	26	5.41	5.45	1.80	0.48
Al	13	4.90	4.94	3.38	0.27
Ca	20	7.64	7.70	3.55	0.33
Mg	12	1.11	1.12	0.85	0.10
		99.15	**100.00**	**100.00**	

Relative to untreated soil (Fig. 9), a number of new low-to-moderate-intensity peaks formed with lime addition, implying the creation of new compounds. The compounds quartz and montmorrilonite, which have been previously found in untreated soil the peaks of these elements, furthermore, shows a significant reduction. The quartz peak decreased by approximately 3,700 cps in untreated residual soil (Fig. 10) to approximately 2,800 cps with lime treatment (Fig. 10), demonstrates that quartz has been significantly attacked by lime to form silica gels.

V. CONCLUSION

Experimental studies show that lime enhances the weak properties of black cotton soil on the basis of which the subsequent conclusions are made.

Alkaline atmosphere necessary to the pozzolanic reaction is attained by 6 % of hydrated lime.

In addition to the lime amount, the liquid limit value decreases, the plastic limit increases, the shrinkage limit and the plasticity index also decreases The result obtained from the consistency index test reveals the beneficial use of hydrated lime to overcome the weak properties of black cotton soil.

With an increase in lime content from 0 to 10 %, the maximum dry density decreases while the optimum moisture content increases.

It has been noticed that unconfined compressive strength continued to increase with any additional lime content. Test results of unconfined compressive strength demonstrate that as the lime content increases, the strength of the stabilized soil increases for all curing periods. The strength of 10% hydrated lime during the 28 day curing period is 0.65 N/mm^2 compared to 0.25 N/mm^2 of untreated soil.

Experimental analysis indicates a substantial improvement in the CBR value for 4 days of soaking with an increase in the hydrated lime amount.

The swelling properties of the expansive soil clearly show that lime can be viewed a very effective to reduce the swelling behavior.

Microscopic examination by SEM and EDS analysis of the hydrated lime blended soil sample shows the advancement of reaction product patches and the formation of cementitious compound peaks.

VI. FUTURE SCOPE

The effects of hydrated lime on other soil properties such as permeability and consolidation can be evaluated.

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Conflict of Interest. The authors declare that there is no conflict of interest.

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