Bioenzymatic-Lime Stabilization of Different Soils

Amit Joshi and C. H. Solanki

Abstract Soil stabilization in modern era is a prime need as the availability of good land is not possible everywhere. By modifying the properties of soil like the bearing capacity, strength characteristics can be enhanced to meet the design requirements for pavement construction. The conventional methods are time-consuming and are not economically feasible. Hence, there is a need to discover the other possible ways to satisfy the performance as well as economic criteria. Stabilization of soil with bioenzyme along with lime is a very new method to improve the geotechnical properties of the soil. In the present work, the effect of stabilization of two different soils with bioenzymes along with lime has been studied. Locally, available soils are taken, and experimental investigation is carried out. One of the soils is found to be expansive, and another is non-expansive but having very low strength characteristics, so both the soils are fall in category of problematic soil. Optimum dose of bioenzyme and various amount of lime (2, 4, 6, 8%) both used together for stabilization. Appropriate curing period of one, two, and four weeks is provided. The tests are carried out to determine the consistency limits, compaction characteristics, unconfined compressive strength (UCS), California bearing ratio (CBR), Free swell index and mineralogical test is also carried out. The laboratory test results show promising results in terms of strength of the stabilized soil. Strength characteristics like unconfined compressive strength (UCS) and CBR value were improved by 14 times and 8 times to its initial value, respectively, and the soil which was highly expansive became low expansive after treatment. More than 5 times reduction is recorded in FSI value. XRD analysis is also carried out that also justifies the stabilization.

Keywords Bioenzyme · Lime · Stabilization · Black cotton soil · Yellow soil · XRD

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1 Introduction

Soil is an indispensable thing of this nature. It is attached to everyone in several ways. All the basic needs of life, whether it is related to food, clothes, and house, are completed by the soil. Without soil, it is not possible to think about life on this earth. The growing metropolitan cities want a number of good lands for both construction and road development. This is the major issue for the construction industry since most of the good lands have already been constructed.

Many areas of India having soils with high silt and clay contents, low strengths, less bearing capacity and high swelling and shrinkage properties. These negative soil characteristics are generally due to the nature and quality of the fines present in the material. Some soils are having very low strength characteristics and will not sustain any construction if build upon that. On the other hand, expansive soils are also problematic. Expansive soils show swell–shrink behavior with the variation in moisture content due to the presence of some swelling clay minerals like montmorillonite.

Expansive soils mostly present in the arid and the semiarid region of the world and are in abundance where the average annual evaporation is more than the precipitation. They are commonly termed as black cotton soils in India.

These soils cover almost more than twenty percent of the total area in India. These soils are residually made from gneisses, volcanic ash, and sedimentary rocks containing calcareous shale, lime, slates, and sand stones. Most of the central part of India is found with expansive black cotton soil. Black cotton soil poses serious construction problems both to structures and highways.

In such conditions, soil stabilization is best option to modify the soil properties and make soil ready for construction. The stabilizers used for this purpose are bioenzyme and lime. Bioenzymes are organic molecules that catalyze specific chemical reactions. They are basically used in low concentrations. Bioenzyme additives attach with large molecules and that are attracted to the clay mineral's negative surface charge. To reduce the amount of bioenzyme, for obtaining the same degree of improvement, the idea of mixing bioenzyme with lime is taken, and it may be greatly advantageous for purpose as working principles of both bioenzymes and lime can be substituted to each other, and since lime and enzyme use the same mechanism of cation exchange to improve soil properties, the idea of adding both lime and enzyme together in the soil and to investigate the alterations in soil properties seemed feasible.

2 Literature Review

A lot of studies have been done on stabilization of soils with bioenzyme and lime both when they are used separately and also the lime with different solid chemicals. Lime stabilization is used from the time of roman, while bioenzymes are existing

from more than decades. Attempt is made to study the effect when both mixed together. Central Road Research Institute (India) (2003) has done laboratory tests on three different soils, Cuddalore soil, marine clay, and Pondicherry soil, stabilized with TerraZyme which is a kind of bioenzyme. Marine clay had liquid limit of 70%, plasticity index of 30%, and clay portion of 62% with 24% silt. It had optimum moisture content (OMC) of 24.5% and dry density (MDD) of 1.55 Mg/m^3. TerraZyme is added with soil at dose of one liter per 0.5 m^3 of soil. The soil was tested for swelling index, unconfined compression strength, CBR, and indirect tensile strength. It is concluded that there is a good improvement in CBR after four weeks of curing as value goes from 1.2 to 4.5%. 104% increment is gained in unconfined compressive strength after stabilization with TerraZyme and 4 weeks of curing. The indirect tensile strength of the marine clay also gives an improvement after curing of four weeks upon treatment with TerraZyme.

Tewodros (2010) has done study in Ethiopia on expansive soils. He constructed the test sections on a road with expansive subgrade in the Chancho Ginchi road. Different methods of soil stabilization were used (mechanical, chemical stabilization, and lime). The expansive subgrade was mechanically stabilized by adding non-plastic gravel with a 50% proportion by volume, and then, it was compacted for required density. The expansive soil was treated with semi-processed lime using 10% by weight, and then, the expansive subgrade was treated with a combination of TerraZyme and hydrated lime. Nine trial sections were constructed by using different materials. This comparative study on different trial sections exposed that TerraZyme stabilization gives good results.

The idea behind mixing bioenzyme and lime together is that there are many salts that have been used with lime for stabilization. Also, bioenzymes alone are used a lot for stabilization. There is no significant work done on this combination. Although Eujine et al. (2016) conducted a study on the alteration of CBR values in soft soils using enzymatic lime. Natural soil samples were treated and cured with enzyme, lime, and enzyme and lime together. The treated samples were subjected to different laboratory tests. The optimum dosages were obtained based on the results of unconfined compressive strength (UCS) tests. After that, samples were treated with optimum dosages and compacted in Proctor molds and then subjected to CBR tests for different periods of curing. More improvement was noticed in enzymatic lime stabilization of soils instead of lime stabilization and enzyme stabilization of soils. CBR tests were also conducted by altering the percentage of clay in the soil samples. In all tests, enzymatic lime stabilization of soils yields more improvement in properties. Enzymatic lime stabilization of soils can be used for improving the bearing capacity of the subgrade, with noticeable savings on both aggregate and disposal charges. Exposure to water has significantly reduced the CBR of all treated soils, with enzyme treated soil being affected the most. CBR of enzymatic lime-treated soils has improved by more than 450% in unsoaked condition as compared to untreated soils.

3 Materials

Soil

Two types of soil are used for carrying out the investigation. One soil sample is collected from Tapi River Bank near Piplod area of Surat city. This soil is named as black cotton soil (BCS), while other soil samples that are named as yellow soil (YS) are collected near the applied mechanics department (AMD) of SVNIT, Surat. Several tests are performed on both the soils for obtaining their properties and suitability for present work.

Bioenzyme

A commercially available bioenzyme under the trade name TerraZyme is used for the present study. TerraZyme was obtained from Nature Plus Inc., USA, through Avijeet Agencies, Ahmedabad. 200 ml of solution is used to carry out the present work.

3.1 Dosage

Based on the research studies and information given by supplier, a dosage may be taken as ml/m^3 of soil (volume in milliliter is needed to treat 1 m^3 of soil). The baseline dosage for medium to mild plastic soil (PI = 4–12) will be 1 l of TerraZyme for 8–12 m^3 of soil. For this work, three dosages are selected as follows (Table 1).

Lime

Lime is purchased from the local market in form of hydrated lime in packets of 5 kg. The CaO content of lime is 65%, and it is obtained by the test conducted in the laboratory.

Table 1 Dosage of TerraZyme

Dosage	ml/m^3 of soil	Curing period in days
1	200 ml/2.5 m^3	0 day, 7 days, 14 days, 28 days
2	200 ml/2.0 m^3	
3	200 ml/1.5 m^3	

4 Experimental Investigations

Untreated soil is tested for laboratory tests like gradation (sieve and hydrometer analysis), Atterberg limits, moisture content, maximum dry density (MDD), optimum moisture content (OMC), specific gravity, free swell index (FSI), unconfined compressive strength (UCS), and California bearing ratio test (CBR) as per IS code. The finding is tabulated below in Table 2.

5 Test Results of Treated Soil and Discussions

Laboratory tests are done on soil samples after mixing of bioenzyme, and the optimum dose of bioenzyme is decided on the basis of laboratory testing, and then, the various percentage of lime (2, 4, 6, 8) are mixed with that optimum dose of bioenzyme.

Three dosage of bioenzyme alone mentioned in Table 1 are given to each sample, and curing period given is 0 day, 7 days, 14 days, and 28 days. It is found that the highest dose of bioenzyme yields high results; hence, that dose is taken as optimum for bioenzyme. After that, both soil samples are tested with that highest

Table 2 Properties of untreated soils

S. No.	Property	Values	
		Black cotton soil	Yellow soil
1	Specific gravity	2.34	2.70
2	Grain size analysis		
	Gravel (%)	0	0
	Sand (%)	10	13
	Silt (%)	58	70
	Clay (%)	32	17
3	Consistency limits		
	Liquid limit	58	38
	Plastic limit	26	25
	Plasticity index	32	13
4	IS soil classification	CH	MI
5	Optimum moisture content (OMC)	23.92	22.62
	Maximum dry density (MDD) in g/cc	1.578	1.74
6	Unconfined compressive strength (UCS) in KPa	138	173
7	California bearing ratio (CBR) (unsoaked)	3.8	5.3
	Soaked	1.83	3.29
8	Free swell index (FSI)	70.4	20.2

bioenzyme dose along with the various percentage of lime; hence, four dosages are made. Now, again all the tests are done for these total seven dosages. Laboratory testing is done to find the properties like UCS, CBR, and FSI.

Unconfined Compressive Strength (UCS)

From the figure, it can be noticed that the effect of stabilizers is very much significant on UCS value, but the addition of lime yields better results. On the zero day of curing, the results are somewhat limited, but after a period of seven days, the effect is something extraordinary as values get boosted. Expansive soil gets 311% improvement on 7 days curing with dose 3. The initial value which is 138 kPa changes to 568 kPa (Fig. 1).

It is observed that 7 days of curing with bioenzyme recorded some considerable results, but when samples tested for dosage of lime-added bioenzyme, something extraordinary happened. Lime effect is so significant that on 7 days of curing only, 520% increment on initial value is recorded. The best result obtained corresponding to the 6% of lime added after that value again decreased. For higher curing periods that are 14 days and 28 days, the trend of improvement is also similar. At 28 days of curing, bioenzyme dose alone gives almost 1066 kPa value for black cotton soil and 1866 kPa when used with 6% of lime. So for black cotton soil which is expansive soil the UCS value increased from 138 to 1866 kPa which is quite a satisfactory result. In UCS value for black cotton soil, more than 1250% increment is seen which mean initial value becomes more than 13 times (Fig. 2).

Now for another soil, which is a yellow soil more or less same trend is followed just in case of previous soil but here the overall improvement is less in comparison to black cotton soil. The bioenzyme and 4% of lime give more than 30% improvement in the UCS value on zero day of curing only. Further increase in lime decreases the result. If we talk about the final improvement, then the maximum value occur is 1365 kPa in comparison to 173 kPa which is a quite tremendous

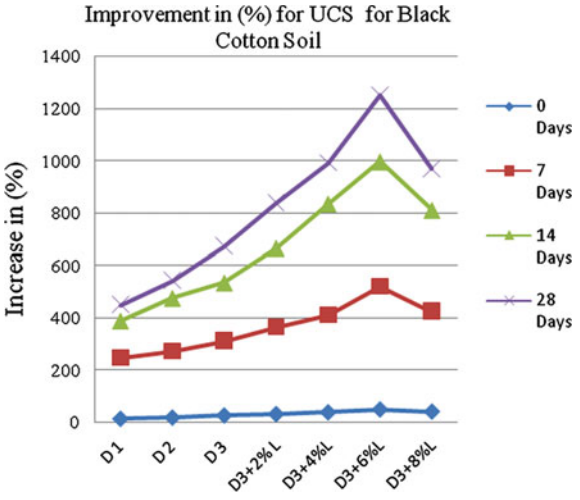

Fig. 1 Improvement in UCS for black cotton soil

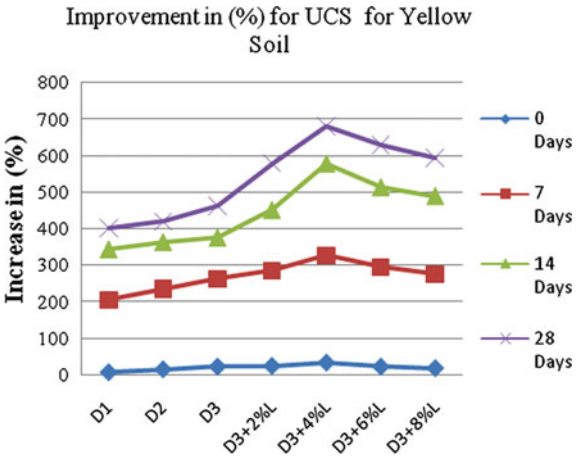

Fig. 2 Improvement in UCS for yellow soil

result and that is obtained with 4% lime used with bioenzyme. 682% of improvement is gained in this case of yellow soil.

It is clearly seen from the results that the initial improvement supposes to happen in both soil samples. For the highest increment in terms of how many times the initial value is changed in first 7 days for both soils, it is observed from Fig. 3 that the gap between the two curves for zero day to 7 days is widest among all curves which shows that here the increment is highest. The gap between 7 and 14 days is good and more or less same as previous gap between curves of zero day to 7 days which shows that here also good increment is recorded. Now from 14 days to 28 days curing, the gap of curves is very narrow which shows that there is an improvement, but it is not that great, but still it is considerable. The rate of improvement is greatly reduced in 14–28 days of curing. Such trends are followed for both the soils, but it is seen that bioenzyme is working almost same with both type of soils, but the overall improvement is something different for both soils as black cotton soil records 14 folds to initial value, while yellow soil shows highest improvement as 8 times only. One thing that is also different for both the soils that is black cotton soil is improved maximum with bioenzyme and 6% of lime, so it is its optimum dose, while yellow soil improves with bioenzyme and 4% of lime; hence, this is its optimum dose. So there is the difference in optimum dosage in two soils when they are treated with bioenzyme and lime both.

California Bearing Ratio (CBR)

For pavement sub base and base course stabilization, CBR is one of the most important parameter as it directly governs the thickness of pavement, so a higher value of CBR is very much desired. The results of untreated soils indicate that CBR values for both soils are quite low, and they need to be increased for any construction work.

The soil samples are prepared, and they are given the particular curing and soaking. In this study, the first set of testing is done after giving samples 3 days of

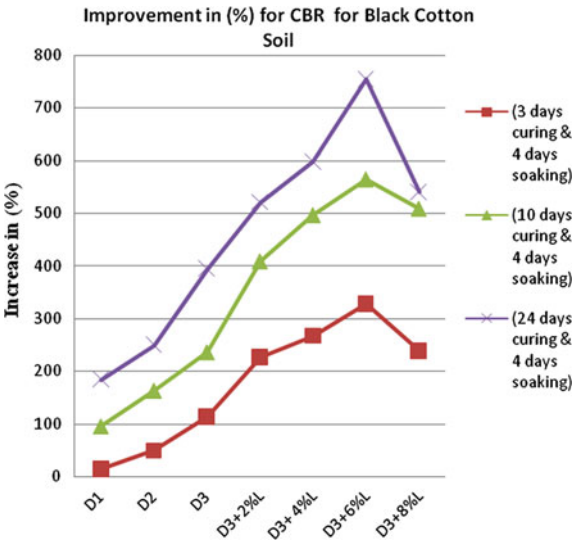

Fig. 3 Improvement in CBR for black cotton soil

curing and then 4 days of soaking, the second set is given 10 days of curing and 4 days of soaking, and for the last set of testing, 24 days of curing and 4 days of soaking are given in particular sequence. On the zero day of curing, CBR value of BC soil for the dose 3 which is the highest dose yields highest improvement, and it is 114% of the initial value. Taking dose 3 as optimum dose of bioenzyme, lime is again added as 2–8%. Now, the lime-added bioenzyme yields some better results than only enzyme as it does for all previously tested properties. Here, the highest improvement comes by bioenzyme with 6% of lime as CBR goes to a value of 7.84 and 329% improvement is recorded. The second set of testing is done for 10 days of curing and then 4 days of soaking. The results obtained here for bioenzyme dosage are quite satisfactory as 236% improvement in CBR value is obtained. For lime-added dosage, CBR reaches to 12.18 from initial value of 1.83 which is a fine result. After that, 24 days of curing and 4 days of soaking are done for the last set of testing. Here, the rate of increase of CBR value is greatly reduced as compared to previous increases, but still it is considerable. For bioenzyme dose, the value is reached to 9.06. The overall a maximum gain in CBR value for black cotton soil is 15.65 from 1.83. The final improvement percentages for lime-added bioenzyme dosage are 521, 598, 755, and 540% for lime 2, 4, 6, and 8%.

Now for the second soil which is yellow soil, the untreated soil has CBR of 3.29. On curing of 3 days and soaking of 4 days, the bioenzyme dose 3 yields maximum gain in CBR value. For the bioenzyme and lime mix dosage, the results obtained are even better as with 4% of lime and enzyme, result improved by 252%. After 4% of lime, if we further increase the percentage of lime, then it starts to reduce the CBR value; hence, 4% lime with enzyme is said to be optimum dose for yellow soil. Now, for second set of testing which means for 10 days of curing and 4 days of soaking, the bioenzyme dosage alone gives results as 7.89, 8.68, and 9.44 for three

dosages. Now, here the improvements in percentage are up to 186%. With addition of lime to enzyme, this improvement goes to 317% and CBR reaches to 13.73. For the final set of testing, the 24 days of curing and then 4 days of soaking are adopted in same manner as mentioned earlier. For that particular set of testing, some great results are noticed as with bioenzyme dosage the initial value of CBR 3.29 reaches to 13.13 which is 300% improvement. So it is observed that the initial value of CBR becomes almost 4 times. Lime and enzyme dosages for this period give CBR value which is maximum among all dosage and curing periods. 397% improvement is recorded in yellow soil for CBR (Fig. 4).

If we summarize the CBR test results, then we have some important points to discuss. If we see the above figures which show the improvement with the help of lines, then we can see that for black cotton soil treated with bioenzyme only, the initial improvement rate for 3 days curing and 4 days soaking is almost same as of yellow soil. Dose 3 of bioenzyme shows almost equal improvement for both soils. But after that period, we can observe that black cotton soil has more overall improvement than yellow soil, and the rate of increment in black cotton soil is also greater than yellow soil. One thing that is common for both the soils is that the rate of improvement for bioenzyme dosage is same for all curing periods which means that the gap between curves is almost of same up to bioenzyme dosage alone, but for lime-added enzyme, this rate is higher in black cotton soil. Coming to optimum dosage for both soils, the bioenzyme dose 3 yields maximum results which is highest dose also for lime-added enzyme dosage; we get different dosage for both soils as optimum. In case of black cotton soil, enzyme with 6% lime yields maximum results, and beyond 6% lime, the values are reduced, while in case of yellow soil, lime 4% is coming out to be optimum dose as beyond that values are

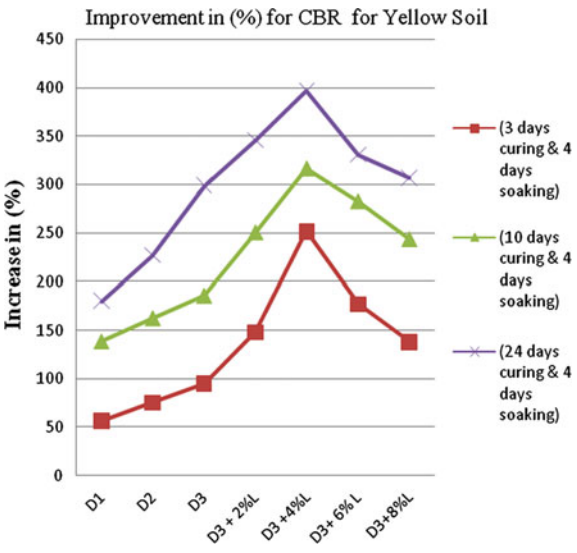

Fig. 4 Improvement in CBR for yellow soil

continually decreasing. Now, we talk about overall improvement; then, it is more in black cotton soil as it gives 750% increment, while in yellow soil, the improvement is restricted up to 400% only.

Free Swell Index (FSI)

Free swell index test is one of the real measures of swelling potential; hence, for expansive soil sample, it is essential to do this test for having the knowledge of swelling characteristics. This test is done on both soils, and it is found that BC soil is having high swelling potential, whereas yellow soil has low swelling potential. Now, again after treatment of soil, free swell index test is done again for both soil samples, and we have got some great results regarding expansive sample. Black cotton soil which initially has FSI value 70% is treated with different dosage and tested for different curing periods. The effect of bioenzyme on FSI value just after mixing is somewhat very limited as we can observe from table also that on zero day curing the maximum reduction is also near to 8% only and even lower dosage unable to show any reduction in value, but the dosage mixed with lime means bioenzyme along with lime show satisfactory results as value comes down to 53 which means 20% reduction happened. After seven days of curing, dose 3 which is highest dose for bioenzyme gives more than 30% reduction in FSI value which is quite a good result. Now, for lime-added enzyme dosage again here 8% lime is giving maximum reduction as 70% of FSI comes to only 30% in just seven days of curing. Here, the difference among the dosage is also quite significant as improvement level is differing by a long margin which is not seen before for other properties. So here also, for zero day to seven day, the rate of improvement is great. Now, for 14 days and 28 days of curing, the rate of improvement is reduced, but still a significant reduction in FSI value is observed. If we talk about the maximum reduction in FSI value, then it is 12 from 70, so 80% reduction is observed which is a great result, but from 14 days to 28 days, the reduction is only 40% (Fig. 5).

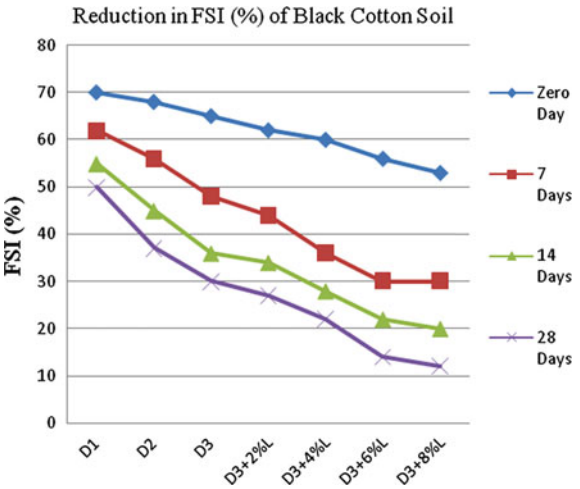

Fig. 5 Reduction in FSI for black cotton soil

Now, if we shift to discussion on yellow soil which has initially the FSI value 20%, then the results obtained are also satisfactory. Initially, there is no or very little improvement as FSI is already not that much high and soil is low expansive only, but lime-added dosage of bioenzyme on curing of seven days reduces the value near to 12% which is a satisfactory result. The further decrement in FSI is not seen after this point

Mineralogical Study

The X-ray diffraction analysis is done on both type of soils and with each bioenzyme and bioenzyme with lime dosage. As we obtained best engineering results for both soils as per of dose 3 of bioenzyme and later it was decided as optimum dose of bioenzyme for these soils, hence Dose 3 treated soils with curing periods of 28 days is taken for XRD analysis as 28 days curing yields maximum results. Now, for bioenzyme with lime dosage, the two soils give different doses as their optimum dose so that the optimum dose of each soil with 28 days of curing again is selected for XRD testing. Which means for black cotton soil dose 3 of bioenzyme along with 6% of lime and for yellow soil dose 3 of enzyme with 4 and of lime was taken. Thus, total of four samples are given for XRD analysis to study the microstructure changes in treated soils.

We know that due to treatment with lime, three major cementations compounds are formed and these are the calcium silicate hydrate (CSH) [$CaO–SiO_2–H_2O$], calcium aluminates hydrates (C–A–H) [$CaO–Al_2O_3–H_2O$], and calcium aluminum silicate hydrate (CASH).

The other compounds present are quartz and montmorillonite, which were originally present in the untreated soil. However, the peaks of these elements also show reduction. The appearance of some new peaks at d-spacing of 4.18–4.26 in both types of soils shows that there is formation of cementations compounds which ultimately governs the development of strength and reducing the swelling behavior. The basal spacing or d-spacing of calcium silicate hydrate (CSH) lies near to 3.04 and 1.82 Å according to the literature available, while the compound calcium aluminum silicate hydrate (CASH) has d-spacing near to 2.250 and 1.988 Å. The reason behind the development of these cementitious compounds is hydration and pozzolanic reaction.

Stabilization with bioenzyme leads to formation of calcium silicate hydrate (CSH) and which can be seen by the appearance of new peaks. Treatment with the bioenzyme and with lime, we get some better results as per of only bioenzyme as here more cementation compounds are formed, and these are the calcium silicate hydrate (CSH), calcium aluminates hydrates (C–A–H), and calcium aluminum silicate hydrate. The formation of new peaks confirms the development of these compounds, and their presence justifies the improvement in soils with these stabilizers.

6 Conclusion

The behavior for strength characteristics through UCS and CBR is predicated, and it is recorded that these values are significantly improved. Although there are variations in the trends of improvement, both stabilizing techniques work for both soils, but black cotton soil shows more improvement. Bioenzyme dosages yield good results, but mixing of lime along with bioenzyme again brings great results. In UCS test, bioenzyme along with lime shows tremendous results as in case of black cotton soil the value becomes 14 times to initial value, while yellow soil shows highest improvement as 8 times. In case of CBR testing overall improvement in black cotton soil as it gives 750% increase while yellow soil improvement is restricted up to 400% only. Expansive characteristics of black cotton soil sample are recorded by FSI value, and there is a great reduction of 80% which brings sample low expansive. Mineralogical study by X-ray diffraction methods also suggests that there are formations of cementation compounds through generation of new peaks.

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