

Influence of Terrazyme on Geotechnical Properties of Lime Treated Black Cotton Soil

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The present paper reports the results of laboratory investigation on effect of terrazyme (TZ) on lime treated black cotton (BC) soil. The soil modified with 2%, 4%, 6%, 8% and 10% of lime is studied to get the optimum content of lime. It is then treated with various different dosages of terrazyme (TZ). Atterberg limits, Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR) and Free Swell Index (FSI) tests were conducted. The liquid limit of the soil lime mixture treated with different dosages of TZ decreases with curing period while the plastic limit and shrinkage limit increases with curing period. UCS of treated black cotton soil continuously increases with curing. CBR of black cotton soil was conducted for optimum dosages of lime and TZ soil mixture. Results show that significance increases in CBR.

Keywords: Black cotton (BC) soil, Terrazyme (TZ), Lime.

1. Introduction

Expansive soils occur in semi arid and arid regions of the world. These soils are very well known for their swell-shrink behaviour whenever there is a change in moisture content (Surekha Naagesh and Gangadhara, 2010). Expansive soils are clays of high plasticity. They predominantly contain montmorillonite clay mineral, which is the most unstable clay mineral. Thus the soils have high expansive nature (Puneth Agarwal and Suneet Kaur, 2014). Expansive soils are problematic because of less strength, low permeability and higher compressibility. Lime is a traditional stabiliser but it has a negative impact on the environment and, thus, its use is discouraged now-a-days (Greshma Nizy Eujine et al., 2017). Bio-enzyme soil stabilizers are available in liquid form and are extracted using vegetables (Muguda Viswanath and Honne Basanna Nagaraj, 2017). Bio-enzyme is an innate, harmless, non-corrosive and incombustible liquid, produced by formulating vegetable extracts. They are

dissolved perfectly in water with the smell of molasses. Soil engineering properties are modified when terrazyme is added to the water and mixed with soil (Puneth Agarwal and Suneet Kaur, 2014). The addition of lime 4 to 6% of lime substantially improves the engineering properties of BC soil (Sailendra Singh and Hemanth B. Vasaikar, 2015). Terrazyme accelerate the reaction between cat-ions and the clay. Thus, catalyse the cationic exchange process to decrease the thickness of adsorbed layer. The Bio-enzymes act on the soil particles and decrease the voids between soil particles and reduce water absorbed in the soil for maximum compaction (Surekha Naagesh and Gangadhara, 2010). Reactive lime changes the soil properties by cation exchange mechanism rather than the binding action brought by pozzolanic reaction. To improve the engineering properties of soil, it is feasible to add TZ and lime together since both uses the same mechanism of cation exchange (Greshma Nizy Eujine et al., 2017).

2. Materials and experimental programme

The BC soil used in the present research work is obtained from Raichur district, Karnataka State, India. Then the soil is powdered in the ball mill and sieved through 425 micron sieve. The geotechnical properties of BC soil are presented in table 1 .Figure 1 show the BC soil used for the present work.

Table 1. Geotechnical properties of BC soil used in present study

Soil property		Value
Distribution of grain size	Percentage of fine sand size	14
	Percentage of silt size	25
	Percentage of clay size	61
Specific gravity of soil solids		2.78
Consistency limits	Percentage of liquid limit	75
	Percentage of plastic limit	31
	Percentage of shrinkage limit	9
Plasticity Index (%)		44
Compaction parameters of IS standards	Percentage of optimum moisture content, OMC	28
	Maximum dry unit weight (MDU) in percentage, (kN/m ³)	14
Free Swell Index (%), FSI		80



Figure 1. BC soil used in the research work

The TZ used in the present work is obtained from the Avijeeth agencies, Chennai, India. They are prominent and authorized suppliers of TZ. The TZ is manufactured by Nature Plus Inc. USA. Terrazyme is bio degradable product made from plant and vegetable extracts. Terrazyme simulates that of the enzymes found in the saliva of termites and white ants which uses it to construct their shelters. It helps in the workability of soil by improving the engineering properties of the soil. The shelters of termites and white ants have withstood the worst climatic conditions of the nature for many decades and proved effective in stabilizing the soils for the construction purposes. The lime for the current research work is collected from the chemical store. The lime used in the present study is sieved through 425 micron before oven dried.

3. Experimental Procedure

All tests were conducted according to procedures specified in respective Indian Standard (IS) code. The consistency limits, UCS and FSI tests on soil modified with 2%, 4%, 6%, 8% and 10% of lime were conducted to find the optimum dosage of lime. Further, optimum dosage of lime-soil mixture is treated with different dosages of terrazyme (TZ₁ to TZ₄) to arrive the optimum dosage of TZ. Finally, optimum dosage of lime and TZ are used to find the California bearing ratio (CBR) value.

4. Results and discussion

4.1 Atterberg limits of BC soil treated with various dosages of lime

The tests were conducted to find the Atterberg limits of soil alone and soil-lime mixture for immediate and 7-day cured sample. Lime is added to soil at an increment of 2% up to 10%. The results obtained are as shown in table 2.

Table 2. Atterberg limits of BC soil treated with lime mixtures for different curing periods

Lime added (%)	Percentage of liquid limit		Percentage of plastic limit		Percentage of shrinkage limit	
	Curing periods		Curing periods		Curing periods	
	Immediate	7- day	Immediate	7- day	Immediate	7- day
0	75	75	31	31	9	9
2	68	70	34	40	15	19
4	59	65	35	45	17	20
6	55	63	35	47	20	27
8	52	60	36	48	21	32
10	50	58	37	48	22	39

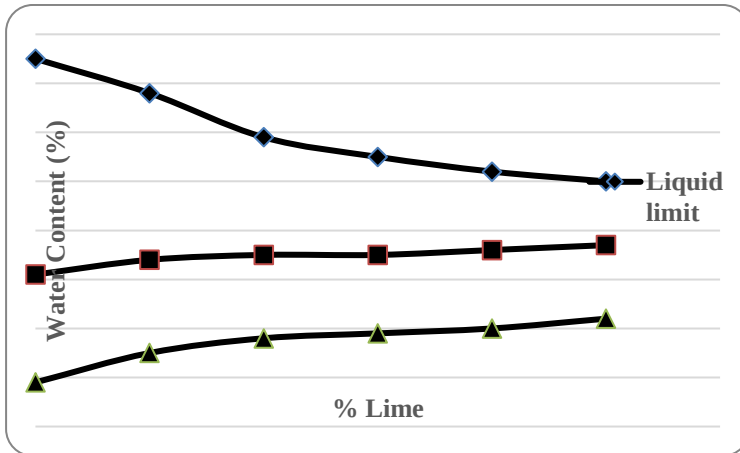


Figure 2. Variation in Atterberg limits of BC soil treated with various dosages of lime for immediate testing

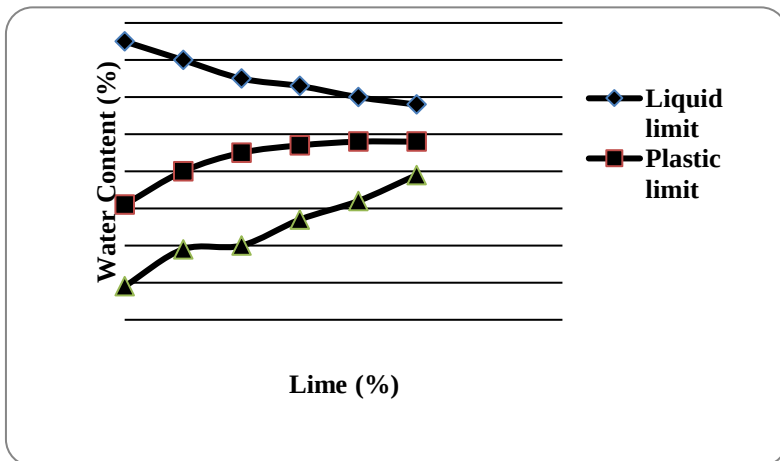


Figure 3. Variation in Atterberg limits of BC soil treated with different dosages of lime for 7-day curing

Figures 2 and 3 show that, the liquid limit of treated soil marginally decreased with the increase in dosage of lime while the plastic limit and shrinkage limit increased for immediate and 7-day curing. This is due to the reduction in surface area, clay content and improved gradation in soil-lime mixtures.

4.2 Compaction behaviour of lime treated BC soil

The variation in MDU and OMC of BC soil treated with various dosages of lime is as shown in figure 4 .

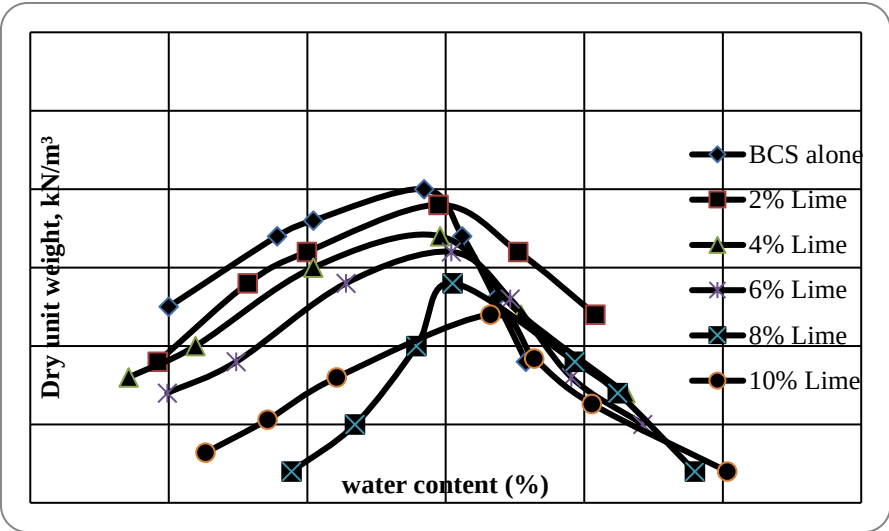


Figure 4. Water content-dry unit weight relation of BC soil for different percentage of lime

From the figure.4 It was observed that , slight reduction in MDU upto 6% addition of lime and beyond 6% ,there is a considerable reduction in MDU. OMC increased slightly upto 6% lime and considerable increase in OMC was observed beyond that point. This is due to the introduction of lime , the soil structure becomes flocculated and water holding capacity increases which results in increasing optimum moisture content

4.3 Swelling behaviour of lime treated BC soil

Free Swelling Index (FSI) is an important property of BC soil and it shows the shrink-swell behaviour of expansive soil. It is the increase in volume of given soil without any external constraint when it is subjected to submergence in water. The variation in FSI for soil treated with different dosages of lime soil mixture are presented in table 3.

Table 3. FSI of BC soil treated with different dosages of lime

Lime content (%)	FSI (%)
0	80
2	67
4	53
6	28
8	20
10	15

Significant variation in FSI was seen when it is treated with various dosages of lime. From the table 3, it can be inferred that free swell index reduces with increase in lime percentage upto 6%. Further increase in lime percentage, no appreciable changes in free swelling index value.

4.4 UCS of lime treated BC soil

The Specimens for UCS tests were cast by adopting MDU & OMC. The specimens were tested after specified curing periods. During the process of curing specimens were stored in desiccators under relative humidity of 100%. Specimens were cast by mixing the BC soil with

lime at 0%, 2%, 4%, 6%, 8% and 10% with particular OMC obtained from compaction test. The variation in UCS with different percentages of lime for different curing periods is as shown in figure 6.

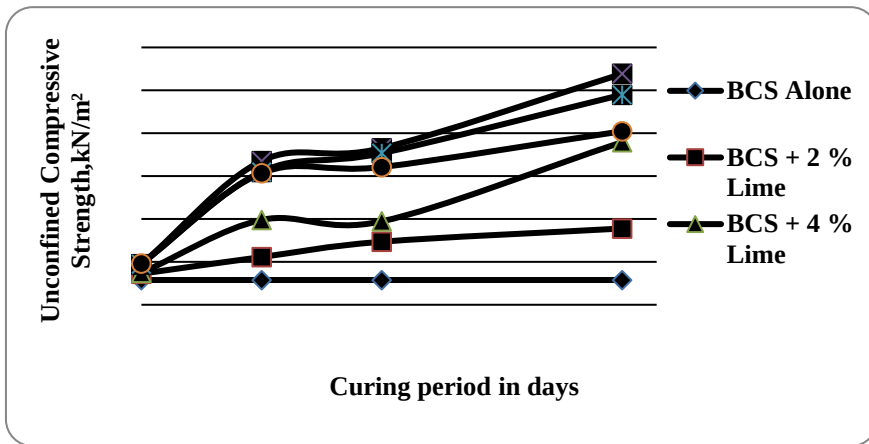


Figure 6. UCS of BC soil alone and BC soil treated with different dosages of lime for different curing periods.

UCS of soil alone tested immediately is 288kPa. Upon curing for a period of 7, 14 and 28 days the strength values do not change. By adding 2% to 10% of lime to the soil the strength increase from 362kPa to 482kPa for immediate testing and further curing the strength has increased from 889kPa to 2023kPa for 28 days curing. From the figure 6, it is observed that specimen treated with optimum content of lime(6%) have appreciable effect on improvement of strength as compared to other dosages. Beyond 6% further increase of lime content does not have greater improvement on strength of soil mass. Soil strength treated with optimum content of lime (Soil + 6%lime) increases with increasing number of curing days, the strength value of the treated soil for immediate testing is 433kPa and for 7, 14 and 28 days curing is 1676, 1825 and 2693kPa respectively. When BC soil is stabilized with lime ,Calicium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) are gelled due to the pozzolonic reaction, and their subsequent crystallization to bind the structure together took place after few days of lime addition. This increase in strength is due to the pozzolonic reactions between the silica and lime, which forms new cementitious compounds C-S-H and C-A-H.

With the above results of Index properties, UCS and FSI, it can be observed that 6% addition of lime decreased the liquid limit and Plasticity Index and increased the unconfined compressive strength significantly. Beyond 6% further increase of lime content does not have the significant effect on the atterbergs limits. The rate of increment in strength for 6% of lime content is higher as compared to the other dosages. Hence, 6% lime (6% L) can be considered as optimum percentage for soil-lime mixture.

Further studies were conducted to find the effect of different dosages of TZ on BC soil treated with optimum content of lime (6%)

4.5 Consistency limits of BC soil + 6% L treated with various dosages of TZ

Based on the above results, 6% lime content is considered as optimum dosage. Further soil-

lime mixture is treated with different dosages of TZ to improve the soil properties to a significant scale. Consistency limits of 6% lime - BC soil mixture treated with different dosages of TZ is found for immediate and 7- day curing period. Results obtained are as shown in table 4. Figure 6 and 7 shows Atterberg limits variation of 6% lime - BC soil mixture treated with various dosages of TZ for immediate and 7-day testing

Table 4. Atterberg limiits of BC soil+6%lime mixture treated with different dosages of TZ

TZ dosage	Percentage liquid limit		Percentage plastic limit		Percentage shrinkage limit	
	Curing periods		Curing periods		Curing periods	
	Immediate	7- day	Immediate	7- day	Immediate	7- day
Nil	55	63	35	47	20	27
TZ d ₁ (200ml/1.5m ³)	54	57	38	41	27	28
TZ d ₂ (200ml/1.0m ³)	53	56	40	43	28	29
TZ d ₃ (200ml/0.5m ³)	51	53	42	44	32	34
TZ d ₄ (200ml/0.25m ³)	50	52	43	46	34	36

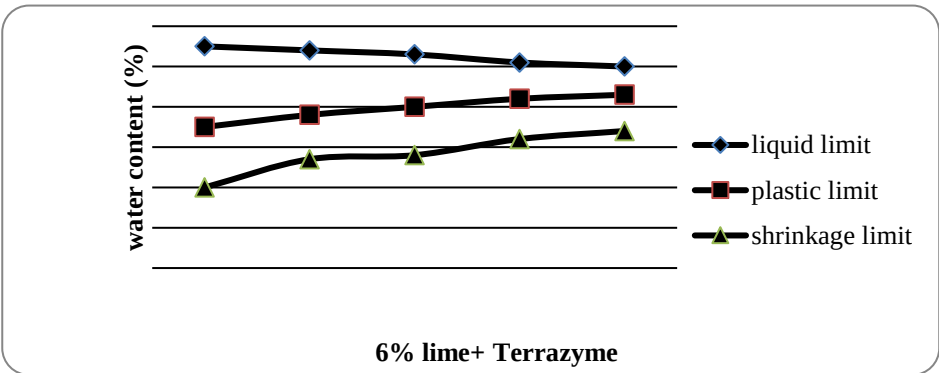


Figure 6. Variation in Atterbeg limits of BC soil – 6% lime mixture treated with various dosages of TZ for immidiate testing

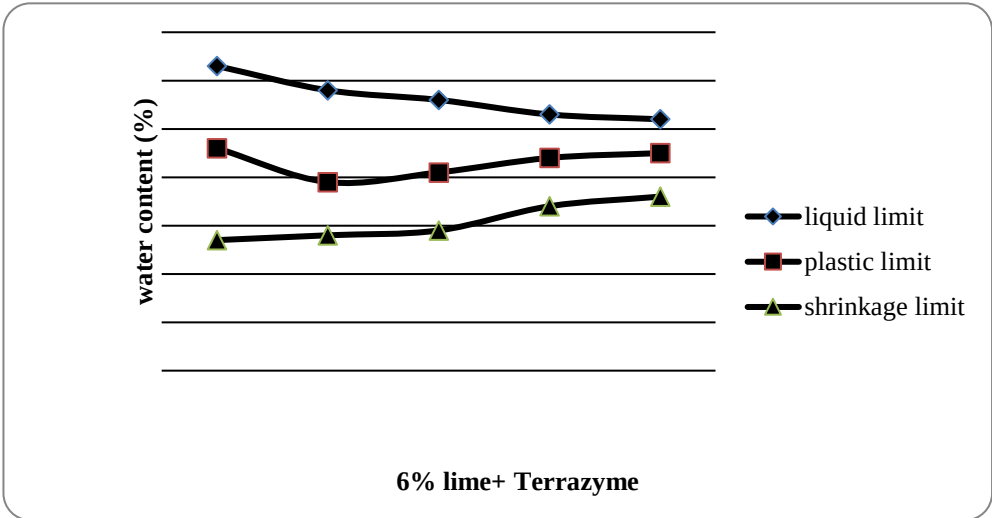


Figure 7. Variation in Atterbeg limits of BC soil – 6% lime mixture treated with various dosages TZ for 7-day testing

From the figures 6 and 7, it was observed that, the liquid limit of treated soil slightly decreased with the increase in dosage of lime while the plastic limit and shrinkage limit increased for immediate and 7-day curing. This is due to reduction in the thickness of diffuse double layer and due to the aggregation of particle caused by the increase in binding of the soil particles due to treatment from Terrazyme and also with the long term of curing period.

4.6 Compaction characteristics of BC soil + 6% lime treated with various dosages of TZ

Compaction test were carried out on BC soil- 6% lime (optimum dosage) mixture treated with TZ content varying from dosage 1 to dosage 4 at an increment of 0.5%. Figure 8 shows water content-dry unit weight relationship for BC soil - 6%lime mixture treated with TZ..

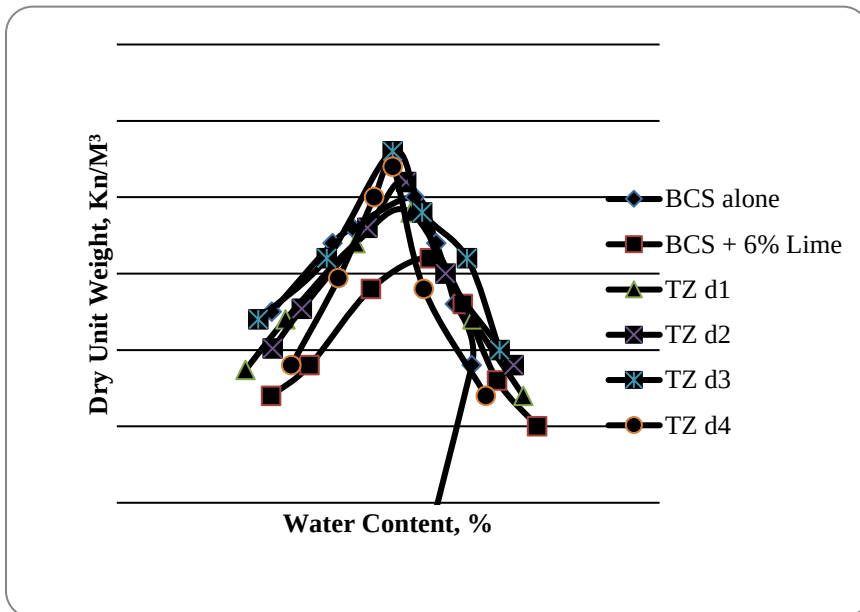


Figure 8. Dry unit weight –water content relationship for BC soil-6%lime mixture treated with terrazyme

Slight increase of maximum dry unit weight upto dosage 3 and considerable reduction beyond that dosage 3 is observed in case of TZ treated (Soil+6%L) mixture. It can be inferred that maximum dry density shows slight variation as shown in figure 8. This may be due to the time required for the TZ to act upon the microorganisms in the soil and then making them to act on the soil. But in the initial portion of the curve shows higher densities of treated soil. Optimum moisture content decreased slightly for all the four dosages with the addition of TZ to (Soil+6% lime) mixture. On addition of various dosages of TZ, the optimum moisture content shows slight variation as shown in figure 8. This may be due to the time required for the TZ to act upon the microorganisms in the soil and then making them to act on the soil.

4.7 Swelling characteristics of BC soil + 6% lime treated with different dosages of TZ

In order to reduce the expansive nature of BC soil to a significant scale further it is treated

with different dosages of TZ. FSI tests were conducted on BC soil - 6% lime mixture modified with four varying dosages of TZ. The variation in swelling for BC soil - 6% lime mixture treated with various dosages of TZ are presented in table 4

Table 4: FSI of BC soil+6% lime mixture treated with different dosages of TZ

TZ Content (%)	Free Swell Index (%)
TZ d ₁ (200ml/1.5m ³)	28
TZ d ₂ (200ml/1.0m ³)	28
TZ d ₃ (200ml/0.5m ³)	23
TZ d ₄ (200ml/0.25m ³)	15

4.8 Unconfined Compressive Strength (UCS) of BC soil + 6% L treated with different dosages of TZ

In this part of research work BC soil under investigation is mixed with 6% lime and treated with different dosages of TZ. Specimens for UCS tests were casted by adopting dry unit weight and moisture content as mentioned. The specimens were tested for 0,7,14 and 28 days curing periods. During the process of curing specimens were stored in desiccators under relative humidity of 100%.

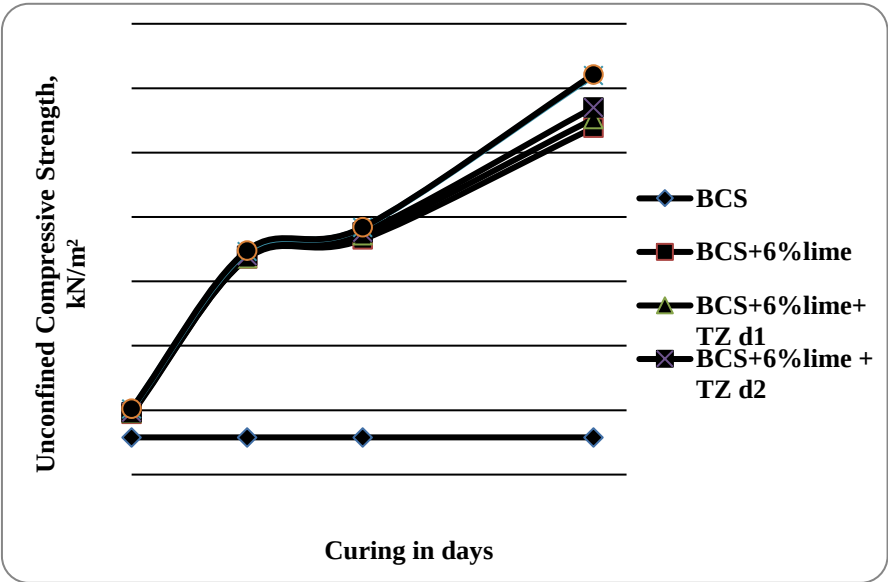


Figure 9: Variation in the UCS of BC soil alone and BC soil+6%lime mixture treated with various dosage of TZ at different period of curing

The strength variations of BC soil-lime mixture treated with TZ have been explained based on the UCS values. As seen from the figure 9, the strength of BC soil-lime mixture (BC soil+6% L) without curing is 433kPa and with curing strength has increased up to 2693kPa for 28 days curing. On addition of 0.1-0.5ml of TZ per kg of BC soil, the strength has increased up to 3107kPa with desiccator curing during 28 days curing of test specimens. Specimens treated with dosage3 and dosage4 achieved up to 70% final strength within 14 days of curing. Specimens treated with dosage1 and dosage2 showed a gradual increment in strength till 28 days curing. The increment in percentage of strength for specimens treated with dosage3 of

TZ was high compared to that of dosage1 and dosage2 while the increment in percentage of strength for specimens treated with dosage4 was not of much appreciable to that of dosage3 over the curing periods. This leads to a conclusion that dosage3 i.e. 0.3ml of TZ per kg of soil is the optimum dosage required to stabilize the BC soil-Lime mixture for strength improvement considering economy in both time and cost of the project.

The strength increment of BC soil-lime mixture treated with TZ after stabilization is due to reduction in the diffused double layer thickness of the diffused double layer at the surface of the clay particles and development of bond between soil particles resulting in agglomeration and flocculation of the clay particles. In desiccator cured specimens, the water removed from diffused double layer enters the pores of the soil which takes some more time to remove water from the pores there by the rate of development of bond is affected.

4.9 CBR of BC soil treated with 6% lime + TZ d₃

In this part of research work tests were carried out on the BC soil alone and treated with optimum dosage of lime (6%) and TZ of dosage3 (TZ d₃) for Unsoaked and Soaked CBR value as per the experimental programme. Specimens were prepared by treating them with optimum dosages of lime and TZ then each of the specimens of BC soil was tested. It was found that CBR value at 2.5 mm penetration is higher than the CBR value at 5 mm penetration. Hence, the CBR value corresponding to 2.5 mm is selected. The variation in CBR values for unsoaked and soaked is as shown in figure 10 and 11.

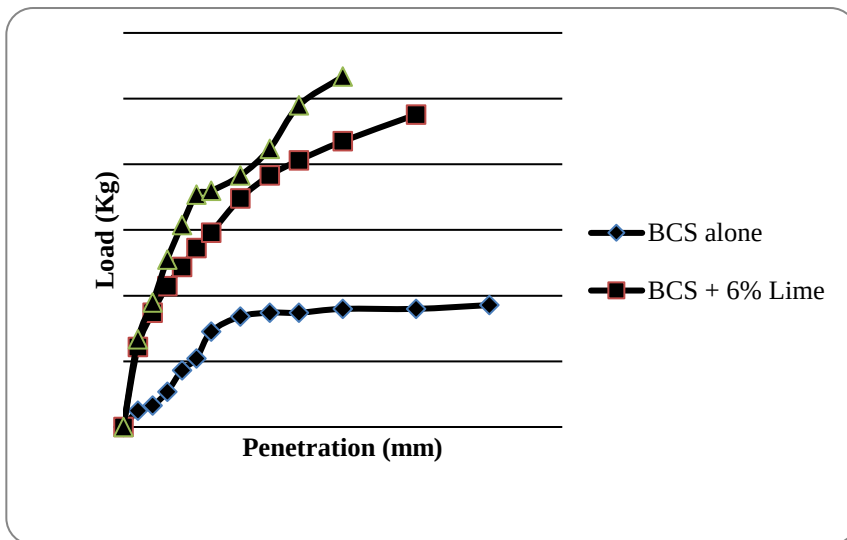


Figure 10. Variation of load and penetration values of Unsoaked BC soil treated with optimum dosage of Lime and Terrazyme.

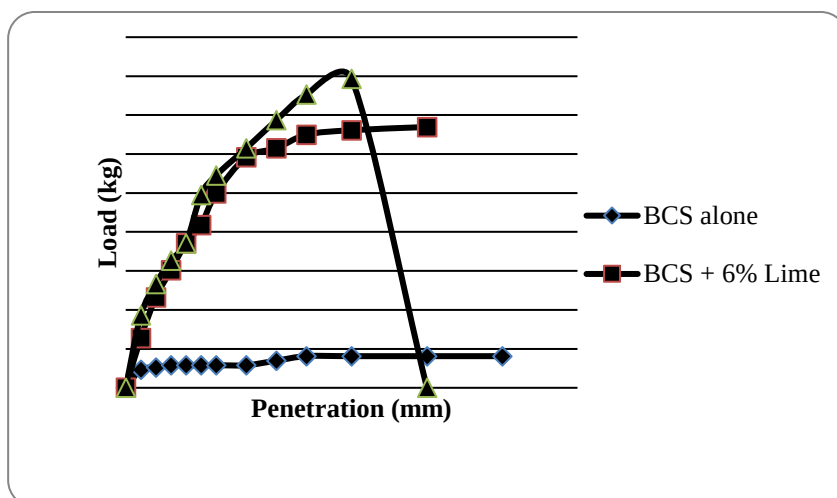


Figure 11. Variation of load and penetration values of Soaked BC soil treated with optimum dosage of lime and TZ

The unsoaked CBR value of black cotton soil alone was 7.5%. When the soil is treated with optimum dosage of lime (6%), the unsoaked CBR value increases up to 19 %. From the figure 10 and figure 11, it was observed that the soaked CBR value of black cotton soil alone was 2.1%. After treating the soil with optimum dosage of lime (6%), the soaked CBR value has increased to 15.2 %. The unsoaked CBR value of the soil-lime (6%) mixture was treated with optimum dosage of terrazyme (TZ d3) specimen increased to 25.8%. Similarly for soaked CBR value of soil-lime (6%) treated with terrazyme (TZ d3) increased to 18%. TZ not only improves the UCS of soils, but also improves the CBR value of soils. Improvement in CBR value of BC soil helps save the cost of road works upto 30% of the whole project cost as proven by many field tests around the globe.

5. Conclusions

From the present study the following conclusion can be drawn.

On treating the BC soil with different dosages of lime, the pasticity index decreases and the shrinkage limit increases. This is due to flocculation of particles that suppressed the thickness of diffused double associated with clay particles. The lime mixture BC soil treated with different dosages of terrazyme results in decreased plasticity index and increased shrinkage limit. This is due to the final reduction in the thickness of diffused double and the aggregation of particle caused by the increase in binding of the soil particles due to treatment from terrazyme. From the results, it can be conclude that, terrazyme has a very little immediate effect on compaction characteristics of lime treated BC soil, due to the time required for the terrazyme to act upon the microorganisms in the soil and then making them to act on the soil.

The FSI test results show that the expansive behaviour of the soil reduces with the addition of lime. 6% lime is considered as optimum content since the percentage decrease in swelling is higher as compared to other dosages of lime. Also, the swelling reduced appreciably for the

soil-lime mixture with the addition of terrazyme. TZ d₃ is considered as optimum content since the decrease in swelling is higher as compared to other dosages of terrazyme. The results of Consistency limits shows that the compaction and FSI of 6% lime stabilized soil mixture and 6% lime stabilized with TZ d₃ soil mixtures are considered as optimal and satisfactory. Upon treating the BC soil with different dosages of lime, the unconfined compressive strength increases upto 6% for all curing periods. Beyond 6% further increase of lime content does not have significant effect on the strength of the soil mixture. But 6 % lime-soil mixture has the better rate of increment and better incremental increase with curing period than the other dosages. On treating BC soil-lime mixture (BC soil + 6% lime) with terrazyme, UCS increases for all dosages of terrazyme at different curing periods. The rate of increment in strength for dosage 3 is higher compared to the other dosages. Considering the Index and unconfined compressive strength aspects, terrazyme dosage 3 (TZ d₃) is concluded as the optimum dosage of terrazyme for treating lime mixed BC soil. The CBR value of both unsoaked and soaked values are increased for lime treated BC soil for about 110% and 325% respectively and the CBR value of both unsoaked and soaked values are increased for black cotton soil-lime mixture (BC soil + 6%lime) treated with terrazyme (TZ d₃) for about 240% and 520% respectively.

However, further studies on the durability of the mixtures are need to evaluate for long-term performance.

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