Mechanical Characterization of a Bio-enzyme Treated Granular Lateritic Soil for Application in Low Volume Roads

Vishal Khanna, Brundaban Beriha, and Umesh Chandra Sahoo

Abstract Traditionally cement, lime and fly ash or combinations of these materials have been used for stabilization of soils and granular materials. Studies on bio-enzyme stabilization suggest that it has the potential to replace these chemicals with more economical as well as environmental friendly solution for potential application in pavement structural layers of low volume roads. Use of bio-enzyme is one such sustainable method which facilitates cation exchange which in turn leads to reduction in adsorbed water on the clay particles. In this, clay (the substrate) is hydrolyzed into calcium silicate hydrate (reaction product), in the presence of bio-enzyme. The formation of reaction product depends upon the concentration of clay particles, dosage of bio-enzyme and environmental factors. In the present study, a commercial bio-enzyme, known as TerraZyme (extracted from sugar molasses) was used with and without addition of cement, to study its effect on strength and durability characteristics of a granular lateritic soil collected from eastern part of India. Effect of curing period, curing temperature and bio-enzyme dosage on the strength and durability properties of the soil was investigated. Mechanical properties of the stabilized soil were evaluated in terms of unconfined compressive strength (UCS) and flexural strength (FS). Results indicate that bio-enzyme is effective in stabilization of granular lateritic soils for application in structural layers of low volume road pavements. However, the strength of the bio-enzyme stabilized specimens under soaked condition needs to be evaluated to recommend it for areas subjected to poor drainage conditions.

Keywords Bio-enzyme stabilization · Unconfined compressive strength · Flexural strength · Durability · Low volume road · Lateritic soil

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1 Introduction

Granular lateritic soils are available in many parts of the world including India and usually this does not meet the specifications for aggregates used in unbound granular layers of pavements. With depletion of the sources of good quality aggregates, it has become imperative to use such marginal materials in pavement structural layers through proper stabilization. Traditionally cement, lime, fly ash have been used for stabilization of soils and granular materials [6, 9, 35]. The major advantage associated with these treatments includes cost effectiveness, readily availability and ease in application [9, 17, 22, 28]. On the flip side, usage of these materials has been found to consume huge human resources or natural resources and at times combination of duo [20, 23]. They are also found to have adverse environmental impacts including emission of huge amount of greenhouse gases, particulate matter, dust and increase in the pH of soil due to the release of OH-ions during hydration [15, 16, 21]. The mechanism of soil stabilization using lime states that lime helps in binding the silicate clay particles by changing their surface mineralogy through the cation-exchange process. This helps in decreasing the plasticity as well as moisture-holding capacity of soil which in turn gives rise to higher stability of soil [4, 24, 26]. Though lime has worked well in this aspect, the adverse effects can't be turned down. Lime carbonation, sulfate-salt reactions and caustic effects are few problems that lead to the weakening and breaking of bonds between the soils particles over the period of time [7, 18, 30]. Moreover, researchers have found that production of one metric ton of portland cement releases approximately one metric ton of carbon dioxide and the production of one metric ton of lime releases about 0.86 metric ton of carbon dioxide making it second largest contributor to humanity's production of greenhouse gas worldwide [16, 31]. At this juncture, there is an urgent need to devise novel techniques and/or substitute these materials partially with certain additives that can effectively strengthen the soil being environmentally cordial. One such newfangled technique is the stabilization of marginal soil by the enzymatic application. The present study focuses on strengthening lateritic soil using bio-enzyme independently as well as combined with cement.

1.1 Enzymatic Mechanism of Soil Stabilization

Enzymes are hydrophilic organic catalyst which do not actively take part in chemical reactions but have a significant role in accelerating the rate of reaction by lowering the reaction activation energy [34] as well as by errand certain geometries in the transition state. Almost all the metabolic pathways in the living organisms are aided by various enzymes which are substrate specific and increase the rate of reaction exponentially [25]. Apart from having a significant role in the body of living organisms, enzymes are also used in the manufacturing of several industrial products. Their applications are well noticed in the brewing, baking and leather industries [19,

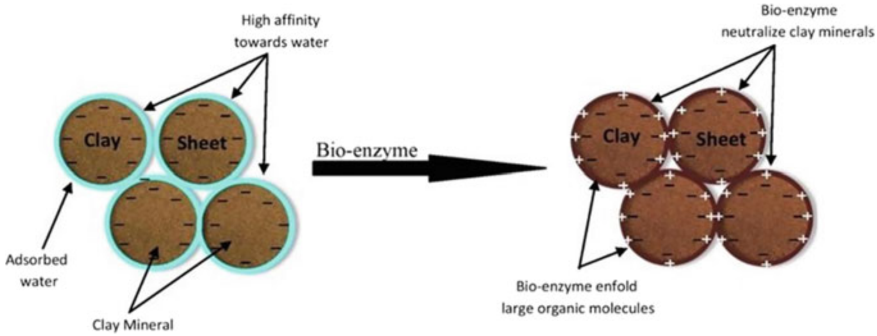

Fig. 1 Enzymatic mechanism of soil stabilization

27, 33]. Enzymatic stabilizer due to advantages like biodegradability, non-toxicity, non-corrosive, ease in handling and ability to reduce carbon footprint have become a subject of interest to the researchers [1, 8]. Enzyme stabilizer agglomerates the clay particles by getting attached on the large organic molecules [5]. These large organic molecules get attracted to the clay minerals due to their net negative charge, which in turn neutralize the negative charge of clay minerals and there-by reducing the water affinity of the same [29, 32]. The above stated mechanism reduces, pore space, swelling and shrinkage, optimum moisture content and increases stability of the soil. In this paper an attempt has been made to evaluate the stabilization effect of bio-enzyme at different dosage, curing time and temperature on the lateritic soil. Figure 1 shows illustration of clay mineral affinity toward water, adsorbed water, enfolding of large organic molecules due to bio-enzyme leading to neutralization of clay mineral.

2 Materials and Methodology

2.1 Materials

Lateritic Soil. Granular lateritic soil sample was procured locally from the state of Odisha, India (20.17040N, 85.70590E). While collecting the soil samples, sufficient care was taken to obtain the representative sample from a reasonable depth after removing the vegetation and trimming the top layer of organic soils.

Bio-enzyme. A commercially available bio-enzyme product, named as TerraZyme (5X) was procured from M/s Avijeet Agencies, Chennai, India. Bio-enzyme is a non-flammable, non-toxic, non-corrosive, liquid enzyme manufactured from fermentation of vegetable extracts (Sugar molasses). Since, these enzymes do not directly take part in the reaction and are found to be highly substrate dependent very little quantity is requisite, making them economical for the pavement application.

2.2 Methodology

Procured soil samples were air dried for seven days succeeded by wet sieving to have precise particle size analysis, as per IS 2720 (Part-4). Particle size distribution curve of the soil sample is shown in Figure 2. To ensure uniform gradation for soil specimens, the grading were reproduced each time. Engineering properties of the tested soil and TerraZyme are shown in Tables 1 and 2, respectively.

Remolded samples for Unconfined Compressive Strength (UCS) on specimens of 100 mm diameter and 115 mm height, Flexural Strength (FS) on specimens of size 75 × 75 × 285 mm were prepared at maximum dry density (MDD) optimum moisture content (OMC) with varying dosage of the bio-enzyme. In order to avoid loss of moisture through evaporation, samples were wrapped with polythene for different curing periods. Four dosages the bio-enzyme (denoted as D1, D2, D3, and

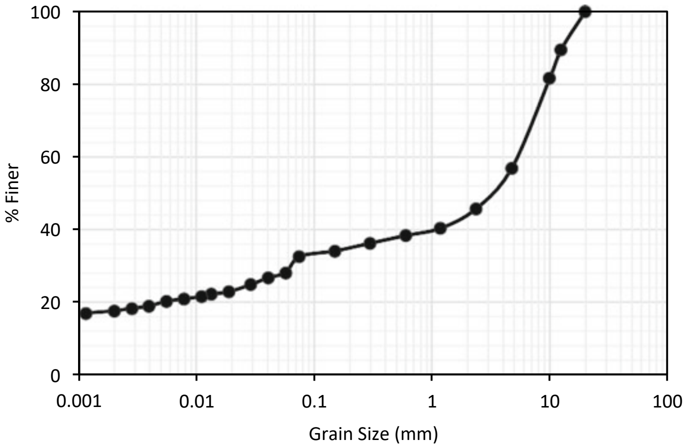

Fig. 2 Particle size distribution of the lateritic soil

Table 1 Engineering properties of lateritic soil

Properties	Results	Reference code
Specific gravity	2.75	IS 2720: Part III:1980
Maximum dry density (MDD)	20.01 (KN/m^3)	IS 2720: Part VIII: 1980
Optimum moisture content	10.95%	IS 2720: Part VIII: 1980
Liquid limit	50	IS 2720: Part V: 1985
Plastic limit	23	IS 2720: Part V: 1985
Plasticity index (PI)	27	IS 2720: Part V: 1985
Classification	SC: clayey sand	IS 1498:1970

Table 2 General properties of bio-enzyme

Properties	Result
Specific gravity	1–1.08
Color	Dark brown
Solubility in water	Close to 100%
Boiling point	212 F
Rate of evaporation	Same as water

D4) was considered initially to determine the optimum dosage based on the UCS value. D1, D2, D3 and D4 correspond to 0.0019, 0.0023, 0.0028 and 0.0038 percent by weight of sample respectively. The dosage that yielded highest average UCS after 1, 2, 4, 8 weeks was deemed as optimum dosage and was further considered for other tests. The detailed experimental investigation has been presented in a graphical form in Figure 3.

Cement with different dosages, i.e. 2% (C1) and 3% (C2) by weight of soil sample was used in combination with D2 and D3 enzyme dosages. Hereby, the above mentioned combination is called as enzymatic cement. UCS and FS were performed as per ASTM D1633 [2] and ASTM D1635 [3] respectively. Durability test was performed in accordance to method 1 described in IRC SP: 89 [10] for stabilized material. To study effect of temperature on the rate of gain of strength, samples were kept in incubator at 30, 40 and 50 °C with 98% humidity to avoid loss of moisture

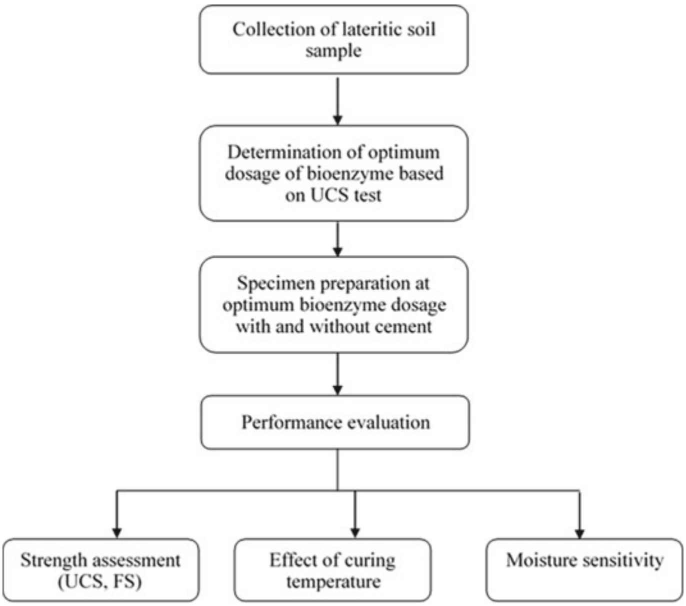

Fig. 3 Flow chart showing the details of the experimental investigation

for 7 days. After their respective curing time, samples were removed from incubator and were tested within 60 min.

3 Results and Discussion

3.1 UCS and FS

Figures 4 and 5 show the strength gain in terms of UCS and FS respectively, for the samples treated with varying dosages of bio-enzyme and enzymatic cement. Significant improvement in the strength with the period of curing is clearly visible in case of both bio-enzyme and enzymatic cement treated samples. The above stated improvement may be attributed to the encapsulation of clay mineral by the large

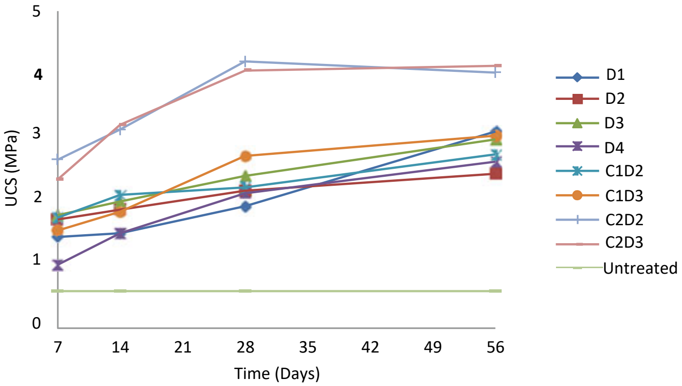

Fig. 4 UCS at different curing time of samples treated with different Bio-enzyme and enzymatic cement dosage

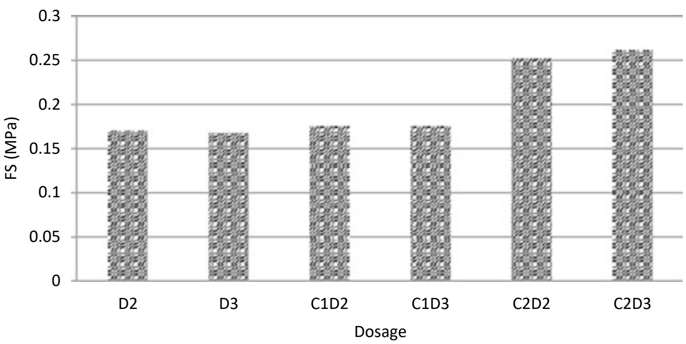

Fig. 5 Flexural strength of enzymatic stabilized soil sample after 28 days of curing

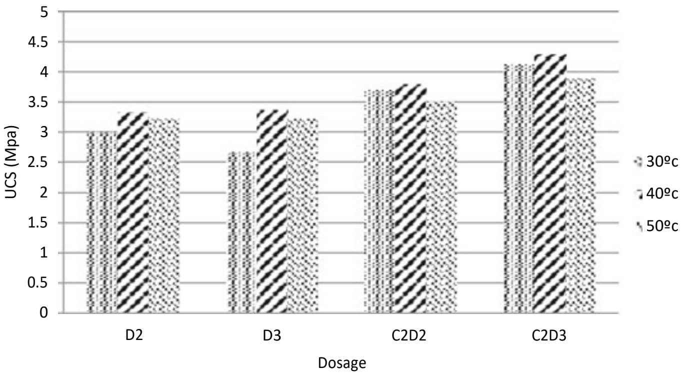

Fig. 6 Effect of temperature on the UCS

organic molecules that reduced its affinity toward water and due to the formulation of calcium silicate hydrate gel. Aforementioned mechanism also leads to reduction in inter-particle space, void ratio, moisture holding capacity, plasticity, swelling and shrinkage making them some of the prime factors leading to strength gain [1, 8].

3.2 Effect of Curing Temperature

In order to further investigate the effect of curing temperature on the enzymatic reaction, seven day incubated samples were tested for UCS. Figure 6 shows 7 day UCS result of enzymatic treated sample incubated at various temperatures. It may be observed that at 40 °C, the rate of enzymatic reaction is better, which led to higher strength. A decrease in strength was also observed with increase in temperature beyond 40 °C. Moreover, influence can be seen greatly dependent on the initial bio-enzyme dosage, higher reduction in strength was seen in the samples treated with higher enzyme dosage. To have a better analysis microscopic studies are suggested for the future work.

3.3 Moisture Sensitivity

Specimens prepared with D3 and C2D3 dosages (three for each) were cured for 7 days and then immersed in water to check the moisture sensitivity. Initial signs of disintegration of the specimens were observed after one day of immersion. This indicates that bio-enzyme treated soils do not have enough structural integrity at 7 days of curing and therefore needs to be cured for longer durations and also efforts should be made to enhance the performance of the enzyme stabilized specimens in presence of water, so that the same can be recommended for areas experiencing long hours of submergence.

4 Conclusions

Both enzyme and enzymatic cement stabilized samples resulted in strength values, which can be suitably used for sub-base and base layers of low volume road pavements. The major advantages associated with the use of enzyme treatment are ease of handling, environment friendly and reasonable price. From the laboratory tests conducted on the same soil with only 3% cement, the UCS value after 28 days was found to be around 2 MPa compared to 4.13 MPa obtained from enzymatic cement stabilization. However, it is recommended to go for stabilization only with bio-enzyme if the desired strength is achieved, else addition of cement or lime may be considered. UCS test results indicated that TerraZyme dosage of 0.0023–0.0028% by weight the soil is optimum and increase in strength with addition of cement was observed. While examining effect of curing temperature, 40 °C was found to be the most favorable temperature for the reactions to take place. However, the strength of the bio-enzyme stabilized specimens under soaked condition needs to be evaluated to recommend it for areas subjected to poor drainage conditions.

References

1. Agarwal P, Kaur S (2014) Effect of bio-enzyme stabilization on unconfined compressive strength of expansive soil. Int J Res Eng Technol 3(5):30–33
2. ASTM D 1633 (2017) Standard Test Methods for compressive strength of molded soil-cement cylinders. ASTM International West Conshohocken, Pennsylvania
3. ASTM D1635/D1635M (2012) Flexural strength of soil-cement using simple beam with third-point loading. ASTM International West Conshohocken, Pennsylvania
4. Bell FG (1966) Lime stabilization of clay minerals and soils. Eng Geol 42(4):223–237
5. Choudalakis G, Gotsis AD (2009) Permeability of polymer/clay nanocomposites: a review. Eur polym J 45(4):967–984
6. Croft JB (1967) The structures of soils stabilized with cementitious agents. Eng Geol 2(2):63–80
7. Eujine GN, Chandrakaran S, Sankar N (2017) Accelerated subgrade stabilization using enzymatic lime technique. J Mater Civ Eng 29(9)
8. Greeshma C, Varun R, Sreekumaran E (2017) Supplementation of zinc induces retinoic acid-mediated differentiation of rat bone marrow mesenchymal stem cells (MSCS) in to insulin producing cells (IPCS) in-vitro. Int J Res Ayurveda Pharm 8 (Suppl 1)
9. Herrin M, Mitchell H (1961) Lime-soil mixtures. Highw Res Board Bull 304
10. IRC: SP 89 (2010) Guidelines for soil and granular material stabilization using cement, lime and fly ash. The Indian Roads Congress, New Delhi, India
11. IS: 2720 (Part III) (1980) Determination of specific gravity. Bureau of Indian Standards, New Delhi, India (Reaffirmed 2002)
12. IS: 2720 (Part V) (1985) Determination of specific liquid limit and plastic limit. Bureau of Indian Standards, New Delhi, India (Reaffirmed 2006)

13. IS: 2720 (Part VIII) (1983) Determination of water content-dry density relation using heavy compaction. Bureau of Indian Standards, New Delhi, India (Reaffirmed 2006)
14. IS: 1498. 1970 (Reaffirmed 2002) Classification and identification of soils for general engineering purposes. Bureau of Indian Standards, New Delhi, India
15. Jawad IT, Taha MR, Majeed ZH, Khan TA (2014) Soil stabilization using lime: advantages, disadvantages and proposing a potential alternative. Res J Appl Sci, Eng Technol 8(4):510–520
16. Joel M, Agbede IO (2010) Mechanical-cement stabilization of laterite for use as flexible pavement material. J Mater Civ Eng 23(2):146–152
17. Kennedy TW, Smith R, Holmgreen Jr RJ, Tahmoressi M (1987) An evaluation of lime and cement stabilization. Transp Res Rec 1119
18. Khalid N, Arshad MF, Mukri M, Kamarudin F, Ghani AHA (2014) California bearing ratio (CBR) value for banting soft soil subgrade stabilized using lime-pofa mixtures. Electron J Geotech Eng 19:155–163
19. Kirk O, Borchert TV, Fuglsang CC (2002) Industrial enzyme applications. Curr Opin Biotechnol 13(4):345–351
20. Kirsch K, Bell A (eds) (2012) Ground improvement. CRC Press
21. Leip A, Billen G, Garnier J, Grizzetti B, Lassaletta L, Reis S, Simpson D, Sutton MA, Vries W, Weiss F (2015) Impacts of European livestock production: nitrogen, sulphur, phosphorus and greenhouse gas emissions, land-use, water eutrophication and biodiversity. Environ Res Lett 10(11)
22. Mainfort RC (1955) Soil stabilization with resins and chemicals. Highw Res Board Bull 108
23. Mitchell JK (1970) In-place treatment of foundation soils. J Soil Mech Found Div 96(1):73–110
24. Mohammadinia A, Arulrajah A, Haghighi H, Horpibulsuk S (2017) Effect of lime stabilization on the mechanical and micro-scale properties of recycled demolition materials. Sustain Cities Soc 30:58–65
25. Rajoria V, Kaur S (2014) A review on stabilization of soil using Bio-enzyme. Int J Res Eng Technol. https://doi.org/10.15623/IJRET.2014.0301011
26. Rosone M, Celauro C, Ferrari A (2018) Microstructure and shear strength evolution of a lime-treated clay for use in road construction. Int J Pavement Eng 1–12
27. Rouau X (1993) Investigations into the effects of an enzyme preparation for baking on wheat flour dough pento-sans. J Cereal Sci 18(2):145–157
28. Sariosseiri F, Muhunthan B (2009) Effect of cement treatment on geotechnical properties of some Washington State soils. Eng Geol 104(1–2):119–125
29. Scholen DE (1995) Stabilizer mechanisms in nonstandard stabilizers. In: Transportation research board conference proceedings (No. 6)
30. Sherwood P (1993) Soil stabilization with cement and lime. State of the art review. Technical Report, Transport Research Laboratory, HMSO, London
31. Thangaraj R, Thenmozhi R (2013) Industrial and environmental application of high volume fly ash in concrete production. Nat Environ Pollut Technol 12(2):315–320
32. Tingle J, Newman J, Larson S, Weiss C, Rushing J (2007) Stabilization mechanisms of nontraditional additives. Trans Res Rec: J Transp Res Board 1989:59–67
33. Van Der Maarel MJ, Van der Veen B, Uitdehaag JC, Leemhuis H, Dijkhuizen L (2002) Properties and applications of starch-converting enzymes of the α-amylase family. J Biotechnol 94(2):137–155
34. Venkatasubramanian C, Dhinakaran G (2011) Effect of bio-enzymatic soil stabilization on unconfined compressive strength and California bearing ratio. J Eng Appl Sci 6(5):295–298
35. Wang JWH, Mateos M, Davidson DT (1963) Comparative effects of hydraulic, calcitic and dolomitic limes and cement in soil stabilization. National Research Council. Highw Res Rec Bull 59:42–54