Kochi Chapter

Indian Geotechnical Conference
IGC 2022
15th – 17th December, 2022, Kochi

Influence of Bio-Enzyme on Compaction and Strength Characteristics of Black Cotton Soil in Nagpur (Maharashtra)

Divya Shanu [1] and Parbin Sultana [2][0000-0002-1241-4302]

[1] M.Tech Scholar, Department of Civil Engineering, National Institute of Technology Silchar-788010
[2] Assistant Professor, Department of Civil Engineering, National Institute of Technology Silchar-788010
parbin@civil.nits.ac.in

Abstract. Soil stabilization is an effective method for increasing the strength and durability of expansive soils like the black cotton soil. The process involved in the soil stabilization should be such that the end product becomes easily workable and environment-friendly. A Bio-enzyme named TerraZyme proves to be a good option for this issue as it is naturally made, safe, biodegradable liquid which significantly enhances the strength of soil by diminishing the size of voids. It improves the compaction of soil with minimal compactive efforts and its effect is long lasting. This paper presents an experimental investigation on the stabilization of black cotton soil using TerraZyme. The dosages of TerraZyme were taken from 200 ml/m³ to 600 ml/m³ of soil and the tests were conducted after 28 days of curing. It is observed that the OMC decreases and the MDD increases with the increase of TerraZyme content. The UCS value increases initially and then starts decreasing after reaching a peak value as the dosage of TerraZyme has been increased. From these observations, an optimum amount of TerraZyme content is worked out for black cotton soils. This optimum enzyme dosage is supported or validated by the FESEM images of treated and untreated soils.

Keywords: Black cotton soil, TerraZyme, Stabilization, Expansive soil.

1 Introduction

Expansive soils are those soils which swell rapidly on encounters with water from outside and shrink noticeably on the removal of it. The phenomenon of swelling and shrinkage is a character of most of the soils (except sands and gravels). But it is exhibited to a very measuring degree only in certain clayey soils. Those soils are usually termed as expansive soil. Expansive soils are sufficiently hard in the dry state and contain a high shear strength which decreases rapidly with the increment of water content. The characteristic of seasonal volume changes associated with such soils causes damage to the structures constructed upon it in the form of cracks, differential settlement and even total collapse at times. In India, the most common expansive soil is known as the Black Cotton (BC) soil, which is found in the central part of the country.

Soil stabilization is the process by which certain engineering properties of a soil are enhanced to meet the geotechnical requirements of the soil for a particular project. It is always desirable that the soil stabilization process is cost-efficient, environment-friendly, and sufficiently effective. The most common properties of a poor soil, which are needed to be improved by soil stabilization are plasticity, Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR) and shear strength. Proper stabilization may improve such properties up to 4-6 times at a bearable cost. There are various additives which can be used for soil stabilization such as surfactants, biopolymers, synthetic polymers, copolymer-based products, cross-linking styrene-acrylic polymers, tree resins, ionic stabilizers, fiber reinforcement, calcium chloride, calcite, sodium chloride, magnesium chloride, etc. In this study, the enzymatic stabilization is observed with the particular enzyme i.e., TerraZyme.

2 Soil Stabilization with Enzyme

Enzymes are organic components which act as catalyst in some of the chemical reactions occurring at the surface of the soil particles. They fasten up the chemical reactions in between the soil particles and the ions present in pore water. Bio-enzymes are natural products prepared through fermentation of vegetable extracts. They are inflammable, non-corrosive and non-toxic in nature, and, therefore can be used safely and conveniently as a stabilizer. There are several forms of enzymes like TerraZyme, Perma-Zyme, Fujibeton, Renolith, etc. Different enzymes have different properties and may be applied to achieve specific desired purposes.

2.1 TerraZyme

TerraZyme is a water-soluble liquid protein, brown in color, and has a smell like molasses. It can be safely handled with hand without using the masks and gloves. It is diluted with water and the solution is mixed with soil at the optimum moisture content. A major advantage of TerraZyme is that it is environment friendly, and is not harmful to animals and marine life. It is durable and has a very low maintenance cost. The treated soil becomes water-resistant and also resists deformation. TerraZyme should be stored at a temperature below 74° for best results. In India, it’s purchase for commercial use is not easy as it has to be ordered only at a few specified agencies. The transportation and storage also need proper monitoring to maintain the temperature.

2.2 Mechanism of TerraZyme Treatment

The clay particles in soil possess negative charge on their surfaces, and thus attract positively charged metal ions present in water. Therefore, a film of water, called the adsorbed water is formed covering the soil particles which attribute to the high water-absorption capacity of clayey soils. TerraZyme releases the positively charged metal ions in to the free water and thereby reduces the thickness of the adsorbed water layer. Due to this, the voids in the soil get reduced and consequently the soil density increases and its permeability decreases. It makes the compaction process easier, i.e. more compaction can be achieved with the same compactive effort. Also, TerraZyme binds the organic particles in the soil by forming cementitious compounds. Thus, the shear strength and the CBR value of the soil increases and its plasticity decreases.

3 Literature Review

Application of Bio-enzymes for soil stabilization have been studied by various researchers. Literature are available which study the significance of various Bio-enzymes such as DZ-1X, EarthZyme, TerraZyme, EcoZyme etc. in altering the engineering properties of soil [1, 2]. By growth of biomass in soil, the enzymes can be used to enhance bioclogging and biocementation [3]. Bioclogging means filling the pores in the soil and thus reducing the porosity as well as the hydraulic conductivity. The bioclogging process may be utilized to reduce hydraulic conductivity in dams and dykes, to prevent leakage and erosion in construction sites, to make a barrier for infiltration and soil pollution from landfills etc. On the other hand, biocementation means formation of cementitious materials to increase the shear strength. This property may be used to increase the bearing capacity of the foundations, to enhance the stability of retaining walls and tunnels, to reduce the liquefaction potential etc. Apart from these, the addition of Bio-enzymes may improve other geotechnical properties like plasticity, moisture-density relationship, swelling and shrinkage etc.

Addition of Bio-enzymes have shown improvement in the UCS and CBR values of inorganic clays [4-6]. Ganapathy et. al [7] have treated a mountain soil (classified as clayey sand) with Bio-enzyme. They observed reduction in plasticity index, maximum dry density (MDD) and permeability; and increase in CBR, UCS and shear strength with the increasing enzyme dosage. The expansive soil in India, also known as the black cotton soil, has been successfully treated with Bio-enzymes at various locations such as Central India [8], Surat [5] and Chennai [9].

However, Bio-enzyme stabilization may not be commensurably effective in all types of problematic soils. For the same amount of stabilizer, soils containing lower clay component gain more strength as each clay particle get access to more amount of the stabilizer. On the other hand, the soils having higher amount of clay component require higher dosage of stabilizer for better neutralization and bonding which will lead to strength gain [10]. After an extensive literature survey, Taha et. al [11] have concluded that use of Bio-enzymes may show moderate to significant improvement of geotechnical properties in different types of soils. Therefore, it is important to conduct laboratory tests on the specific soil of a project. If the laboratory tests show desirable improvement, then only one should check it for field applications.

4 Materials and Methodology

4.1 Black cotton soil

For this study, the black cotton soil, which is expansive in nature, was obtained from Ramtek village of Nagpur, Maharashtra (Fig. 1) by open excavation method from a depth of 1 m at an agricultural field. The soil sample was disturbed in nature. It was collected in clean cement bags and stored in a dry place in the laboratory. Soil was used as and when required as per the requirements of the tests. For all the tests the ovendried soil samples were used for maintaining the proper moisture content. The index properties of the soil are shown in Table 1.

(a) Location of the site (b) The collected soil

Fig.1. The location and image of the BC soil

Table 1. Index properties of BC soil

Property	Value
Specific gravity	2.54
Grain size analysis:	
Silt and clay-sized particles (%)	65.4
Sand sized particles (%)	34.6
Coefficient of uniformity of sand portion, Cu	2.86
Coefficient of curvature of sand portion, Cc	0.97
Liquid limit (%)	57.66
Plastic limit (%)	31.43
Shrinkage limit (%)	12.825
Standard Proctor test results:	
MDD (g/cc)	1.599
OMC (%)	22.46
UCS (kg/cm^2)	0.772

4.2 Enzyme-TerraZyme

The enzyme used in this study was TerraZyme and was purchased online from India Mart. The properties of this enzyme, as supplied by the supplier, are shown below in Table 2.

Table 2. Properties of TerraZyme

Property	Values/Details
Boiling point	100^0C
Specific gravity	1.00 to 1.09
Melting point	Liquid
Vapour density	1
pH value	4.30 to 4.60
Appearance/Color	Brown clear liquid
Storage	For maximum effectiveness store below 74^0C
Shelf life	3 years under proper storage conditions
Not flammable	Will not ignite or burn
Hazardous compounds	None
Solubility in water	Complete
Odour	Non-obnoxious
Explosion hazard	None
Contents	Natural surfactants derived from cereal, vegetable extracts and carbohydrates, ferments

4.3 Typical calculation of enzyme quantity

For the calculation of enzyme quantities of all the dosages, the reference MDD value was rounded off to 1.6 g/cc or 1600 kg/m^3 and OMC was 22.46%. A dry density of 1600 kg/m^3 means; the mass of soils is 1600 kg for 1 m^3 volume of soil. Hence, 1 m^3 soil also means 1600 kg of soil.

Let us now consider the first enzyme dosage of 200 ml/m^3. For 1 m^3 of soil or 1600 kg of soil TerraZyme content is 200 ml, and hence for 1 kg of soil TerraZyme content works out to be 0.125 ml. Similarly, the enzyme quantities for all other dosages were calculated. Table 3 gives the enzyme dosages and corresponding quantities adopted in this work.

Table 3. Enzyme dosage details

Enzyme dosage (ml/m^3 of soil)	**Enzyme quantity (ml/kg)**
200	0.125
250	0.156
300	0.187
350	0.218
400	0.250
450	0.281
500	0.312
550	0.343
600	0.375

4.4 Method of enzyme addition to soil samples

For collecting the exact quantity of enzyme, a medical syringe of capacity 1 ml with 0.02 ml of minimum reading was used. The required quantity was sucked using the syringe from the bottle of the enzyme. The bottles of TerraZyme and the medical syringe are shown in Fig. 2.

Fig. 2. TerraZyme bottles and syringe

5 Results and Discussion

5.1 Influence of TerraZyme on compaction characteristics

It is a well-known fact that the soils having lower density are generally treated as weaker or problematic soils. Expansive soils, for example, black cotton soils are known to have lower density i.e., lower MDD and hence higher OMC. It is clear from Table 1 that due to the high liquid limit and plasticity index of the black cotton soil under consideration, it is classified as clay with high plasticity or high compressibility (CH). It has an MDD of 1.599 g/cc which is not an issue, but its OMC is 22.46 %, which is too high. The objective of stabilizing this black cotton soil with enzyme is to increase its MDD and reduce its OMC and render it to be stable and strong soil, and in turn, to improve the volume stability and shear strength of the soil. In this aspect, the results observed are presented in the following section.

As per the enzyme dosages shown in Table 3 the compaction tests were conducted on the black cotton soil. Table 4 shows the variation of MDD and OMC with enzyme dosages and the same is represented in Figures 3 and 4.

Table 4. Variation of MDD and OMC with enzyme dosages

Enzyme dosage (ml/m^3)	**MDD (g/cc)**	**OMC (%)**
0	1.599	22.46
200	1.607	22.17
250	1.607	21.73
300	1.621	19.86
350	1.631	19.83
400	1.652	19.68
450	1.657	19.62
500	**1.664**	**19.30**
550	1.664	19.30
600	1.664	19.30

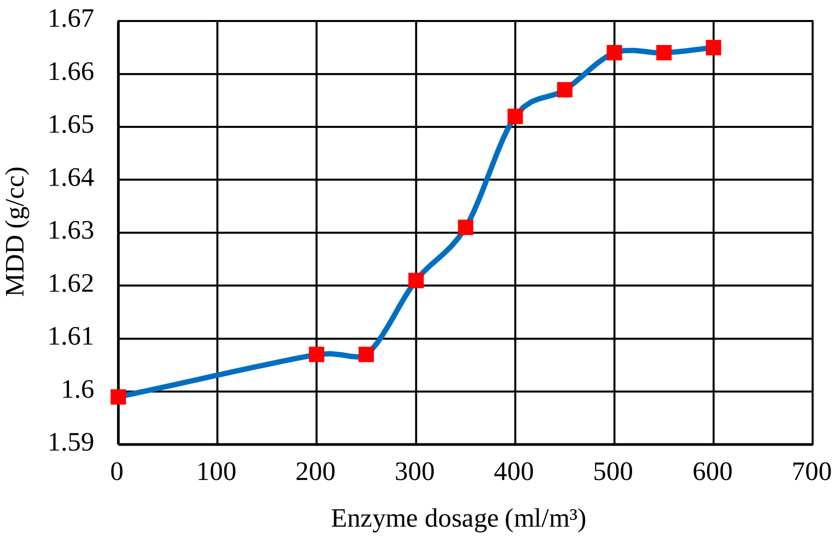


Fig. 3. Variation of MDD with enzyme

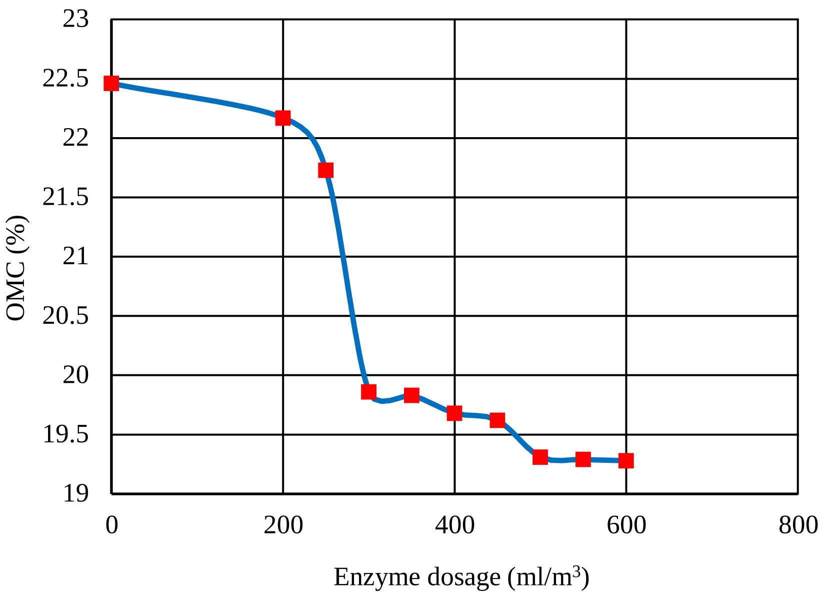


Fig. 4. Variation of OMC with enzyme dosages

The untreated soil has an MDD of 1.599 g/cc. It can be observed from Table 4 and figure 3 that as enzyme dosage is added up to 500 ml/m^3 the MDD increases to a maximum value of 1.664 g/cc and afterward it remains constant. Hence, the optimum enzyme dosage is 500 ml/m^3 for which the maximum value of MDD is 1.664 g/cc.

Similarly, untreated soil has an OMC of 22.46 %. It can be observed from Table 4 and figure 4 that as enzyme dosage is added up to 500 ml/m^3 the OMC decreases to a minimum value of 19.3 % and afterward it remains constant. Hence, the optimum enzyme dosage is 500 ml/m^3 for which the minimum value of OMC is 19.3 %. The optimum enzyme dosage and the best values of MDD and OMC are highlighted with yellow color in Table 4.

5.2 Influence of TerraZyme on unconfined compressive strength

The objective of stabilizing this black cotton soil with enzyme is to increase its shear strength and render it stable or strong soil status, in turn, to improve the volume stability of the soil. As the soil strength increases with passing of time, all the soil samples were kept for 28 days of curing before testing. Table 5 shows the variation of UCS with enzyme dosages and the same is represented in Fig. 5. The maximum amount of UCS obtained is highlighted with yellow color in Table 5.

Table 5. Variation of UCS with enzyme dosages

Enzyme dosage (ml/m^3)	**UCS (kg/cm^2) (Sample after 28 days of curing)**
0	0.772
200	0.798
250	0.933
300	1.358
350	**1.545**
400	1.465
450	1.226
500	1.145
550	1.145
600	1.093

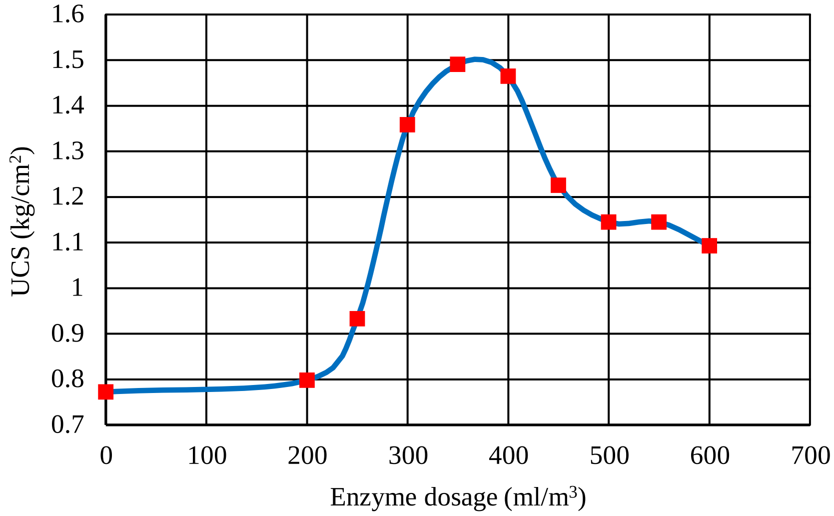
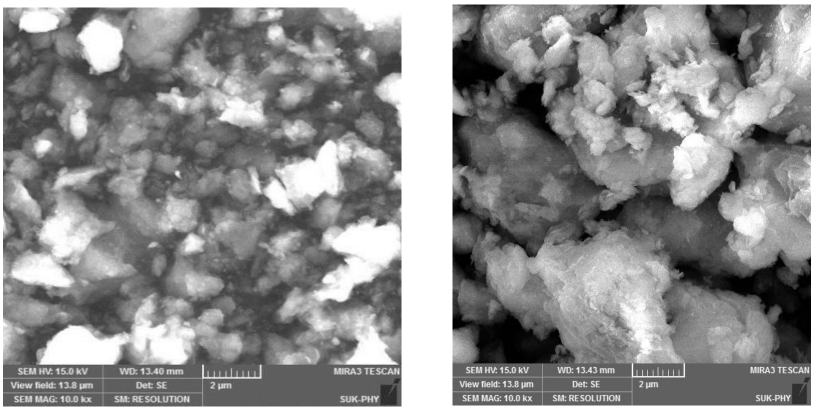


Fig. 5. Variation of UCS with the enzyme

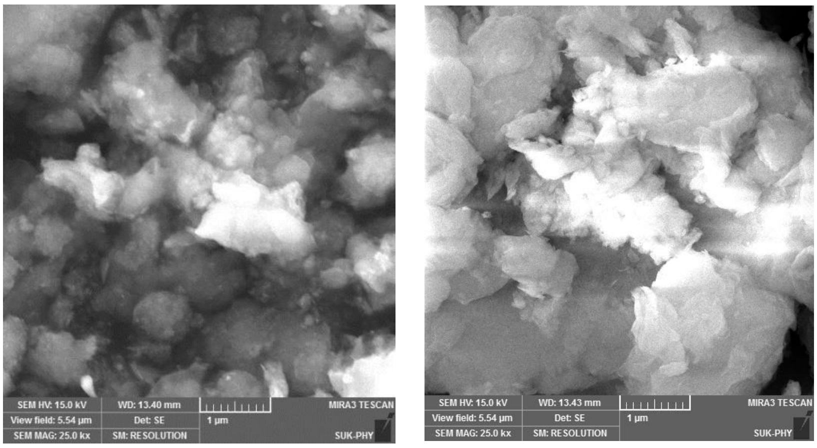
5.3 Comparison of FESEM images of treated and untreated soil

Comparison of the FESEM images of untreated soil and treated soil at 28 days of curing with enzyme dosage of 500 ml/m³ are shown in Fig. 6. The voids can be identified by the dark spaces in between the soil particles. It is evident that the treated soil becomes more homogeneous and agglomerated with fewer voids (or shadows) or more density. The formation of cementitious compounds are also visible in the images of the treated soil.



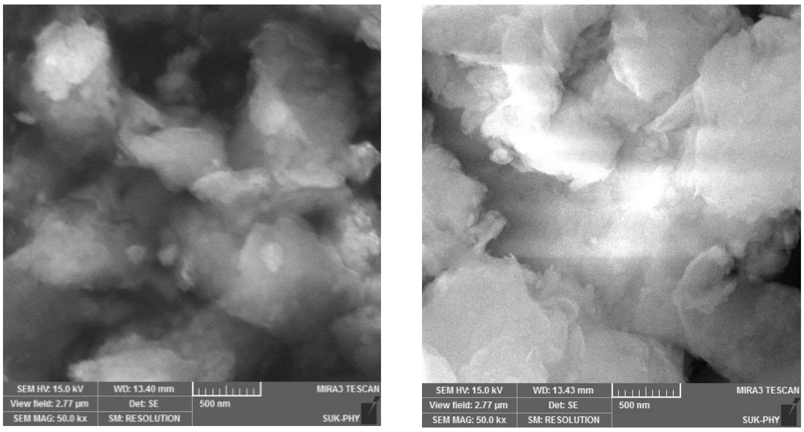
Untreated Treated

(a) Image at 10 kx and 2 µm



Untreated Treated

(b) Image at 25 kx and 1 µm



Untreated Treated

(c) Image at 50 kx and 500 nm

Fig. 6. FESEM images of treated and untreated soil

6 Conclusion

On the basis of the experimental works carried out for the stabilization of black cotton soil using TerraZyme and from the FESEM images the following conclusions can be drawn.

i. The black cotton soil used in this work is clay with high plasticity or high compressibility (CH) as per IS: 1498 method of the soil classification system.

ii. The MDD of untreated soil is 1.599 g/cc and at the optimum enzyme dosage of 500 ml/m^3,' the MDD of treated soil reaches the maximum value of 1.664 g/cc. This shows that the optimum enzyme dosage of 500 ml/m^3 makes a marginal increase of 4.1% in the MDD. Though this increase in MDD is not that great, the overall behavior of black cotton soil has improved.

iii. The OMC of untreated soil is 22.46% and at the optimum enzyme dosage of 500 $ml/m^{3,}$ the OMC of treated soil reaches a minimum value of 19.3%. This shows that the optimum enzyme dosage of 500 ml/m^3 reduces the OMC by 14.1%. This reduction in OMC is very significant, which helped in improving the volume stability of black cotton soil and achieving higher strength.

iv. The UCS of untreated soil is 0.772 kg/cm^2 and at the optimum enzyme dosage of 350 ml/m^3 the UCS of treated soil becomes of 1.545 kg/cm^2. This shows that the optimum enzyme dosage of 350 ml/m^3 the % increase in the UCS is 100.1%. This increase in UCS is very significant and implies that the treated black cotton soil can be conveniently used to resist larger loads or stresses.

v. At the optimum TerraZyme dosages for this black cotton soil, densification and agglomeration of soil particles are observed in the FESEM (Field emission scanning electron microscopy) images.

References

1. Khan, T. A., Taha, M. R.: Effect of Three Bioenzymes on Compaction, Consistency Limits, and Strength Characteristics of a Sedimentary Residual Soil. Advances in Materials Science and Engineering. http://dx.doi.org/10.1155/2015/798965 (2015).
2. Jenith, P., Parthiban, C.: An Experimental Study of Bio-Enzyme on Black Cotton Soil as a Highway Material. International Journal of Engineering Research & Technology (IJERT) 5(13), 1-4 (2017).
3. Ivanov, V., Chu, J.: Applications of Microorganisms to Geotechnical Engineering for Bio-clogging And Biocementation of Soil in Situ. Rev Environ Sci Biotechnol 7, 139–153, DOI 10.1007/s11157-007-9126-3 (2008).
4. Panchal, M., Khan, M. M., Sharma, A.: Stabilization of Soil Using Bio-Enzyme. International Journal of Civil Engineering and Technology (IJCIET) 8(1), 234–237, (2017).
5. Joshi, A., Solanki, C. H.: Bioenzymatic-Lime Stabilization of Different Soils. In: R. Sundaram et al. (eds.), Geotechnics for Transportation Infrastructure, Lecture Notes in Civil Engineering 29, 381-392. https://doi.org/10.1007/978-981-13-6713-7_30 (2019).
6. Venkatasubramanian, C., Dhinakaran, G.: Effect of Bio-Enzymatic Soil Stabilisation on Unconfined Compressive Strength and California Bearing Ratio. Journal of Engineering and Applied Sciences 6(5), 295-298, (2011).
7. Ganapathy, G.P., Gobinath, R., Akinwumi, I. I. et al.: Bio-Enzymatic Stabilization of a Soil Having Poor Engineering Properties. Int J Civ Eng 15, 401–409. https://doi.org/10.1007/s40999-016-0056-8et. al (2017).
8. Agarwal, P., Kaur, S.: Effect of Bio-Enzyme Stabilization on Unconfined Compressive Strength of Expansive Soil. International Journal of Research in Engineering and Technology 3(5), 30-33, (2014).
9. Rajendran, J., Jaisankar, V.: A Study on Stabilization of Expansive Soil Using Terrazyme. International Research Journal of Natural and Applied Sciences 4(6), 110-120, (2017).
10. Ali, F.: Stabilization of Residual Soils Using Liquid Chemical. EJGE 17(B), 115-126, (2012).
11. Taha, R. M., Khan, T. A., Jawad, I. T. et. al: Recent Experimental Studies in Soil Stabilization with Bio-Enzymes–A Review. EJGE 18(R), 3881-3894, (2013).