Effect of Marble Dust and Terrazyme on UCS and CBR Characteristics of Clay Soil

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Abstract

Bio-enzyme is an eco-friendly stabilizing agent, which can be derived from plants and microorganisms. Marble dust, on the other hand, is a by-product of the marble industry. This paper focusses the utilization of marble dust in clay soil stabilization and also the studies carried out to understand the effect of Terrazyme on UCS and CBR of clay soil. Unconfined compression stress (UCS) tests and California Bearing Ratio (CBR) tests were conducted on mixes of clay soil + Terrazyme+ marble dust to bring out the efficacy of the marble dust and Terrazyme on UCS and CBR values of clay soil. The dosages of Terrazyme used in the study are 0.125ml, 0.25ml and 0.5ml per kg of dry soil. The marble dust proportion of 15% is considered constant in all the tests. The results revealed that the UCS of treated clay has increased with increased Terrazyme dosage for all mix proportions and further noticed that the samples subjected to 7 and 14 days curing period resulted in high improvement in UCS of clay soil. This improvement is about 69% and 101% respectively for both 7 days and 14 days cured mixes as compared to the untreated soil. At 0.25 ml/kg of Terrazyme, the UCS and CBR of 28 days cured mix showed better results than the soil treated with 0.5 ml/kg. The microstructural analysis, such as XRD and SEM, showed the formation of C-S-H gel, which resulted in improvement of soil strength and CBR. Overall, use of 0.25ml/kg Terrazyme and 15% marble dust results in higher CBR and UCS for soil and also it eases the utilization of waste marble dust in the construction industry as stabilizing material.

Keywords: Marble dust (MD), Terrazyme, Unconfined compression strength (UCS), standard proctor compaction (SPC) test, California bearing Ratio(CBR)

1. Introduction

Construction and engineering projects must include soil stabilisation since it helps the soil engineering qualities and lessens its susceptibility to deformation, erosion, and other environmental influences. Utilising bio-enzymes and discarded marble powder one such method of stabilising soil. Natural organic substances called bio-enzymes may disassemble complicated molecules and transform them into more manageable forms that can be utilised by plants and other creatures. In addition to other advantages, the use of bio-enzymes in soil stabilisation can boost the soil structure, water-holding capacity and nutritional content.

While cutting, shaping, and polishing marble stones, results in the production of waste marble powder a by-product of the marble industry. Environmental pollution results from the frequent landfill or water body disposal of such solid waste. However, because it can improve the mechanical and physical properties of the soil, the leftover marble powder has been identified to be a useful soil stabiliser. In building and engineering projects, the usage of bio-enzymes with waste marble powder can deliver an efficient and long-lasting solution for soil stabilisation. This strategy not only lessens environmental contamination, but also offers a practical and environmentally beneficial substitute to traditional soil stabilisation techniques.

The efficacy of enzyme stabilized soil was studied and reported the optimum enzyme dosage as 200ml per 1.5 to 2m^3 for CH soils, 200ml per 0.6m^3 for both CI and CL soils. The optimum dosage for CL-ML soils is 200ml/0.5m^3. For MH-soils the dosage reported is 200ml/2-2.5m^3. For ML soils, SP soils, SM-GM soils the optimum dosage was found to be 200ml/2m^3 [1]. Improvement in the characteristics of black cotton soil was reported at the marble dust dosages of 20% to 60% by weight of dry soil. The liquid limit decreased from 31.3% to 23.5%. The plasticity index decreased from 11.57% to 4.35%. The CBR value increased from 10.36% to 27.19%. Marble powder can be used as filler in concrete and paving materials and helps to reduce total void content in concrete [2]. The strength of Enzymatic soil (Ecozyme + black cotton soil) for a curing period of 0days, 7days, 14days, 21days and 28days at various dosages of Ecozyme 200ml/3m^3, 200ml/2.5m^3, 200ml/2m^3, 200ml/1.5m^3 studied [3]. Shear strength and CBR of soil increased with an increase in curing period and dosage of Terrazyme and it was reported as suitable in pavement construction [4]. The results of waste foundry sand admixed clay along with Terrazyme revealed that there is a good improvement in the strength and CBR characteristics of soil when cured for longer periods i.e., 14 days and 28 days [5]. Good quality subgrade can be achieved by adding Terrazyme to the weak subgrade soil [6]. Extensive work was carried out on stabilization of weak subgrade soils using various types of bio enzymes such as Renolith, Permazyme, Terrazyme, and Fujibeton. Also reported the stabilisation processes, benefits, limitations with regard to the durability & stability of soils stabilized with bio enzymes and the impact of these enzymes on the environment [7]. It was reported that the bio-enzymes enhance the engineering properties of soil, enables to obtain more compacted densities of soil, and also ensures the stability of stabilized soil. It was further reported that the bio-enzymes eases simple mixing of water at the OMC for better compaction of soil. Soil stabilized with bio enzymes showed high quality and better performance and resulted in higher CBR values as well as reduced cost of pavement construction and the savings observed are 25% to 40% [8]. In this study, further attempt is made to understand the efficacy of marble dust and Terrazyme combination on strength and CBR improvement of stabilized soil. The procedures adopted and discussion of results is presented below.

2.0 Tests Conducted and Materials Used

In this paper, the tests conducted are presented in Table.1 along with their respective code of conducting the tests. The basic properties of soil and marble dust are presented in Tables. 2 and 3 respectively. Fig.1 shows the various materials used in the study.

2.1 Tests Conducted

Table.1 presents the list of tests conducted along with the respective code number.

Table.1 List of tests conducted

S.No.	Name of the test	BIS Code
1	Specific gravity	BIS 2720: Part 3 (1980)
2	Grain size analysis	BIS 2720: Part 4 (1985)
3	Atterberg limits	BIS 2720: Part 5 (1985)
4	I.S. Light compaction test	BIS 2720: Part 8 (1983)
5	Unconfined Compression Test	BIS 2720: Part 1 (1991)
6	California Bearing Ratio test	BIS 2720: Part 16 (1987)
7	Free Swell Index	BIS 2720: Part 40 (1977)

2.2 Clay

The clay soil used in the study was collected from Ibrahimpatnam Area in Hyderabad, Telangana. The collected soil was oven dried and stored in airtight bags in the laboratory for use in laboratory tests. The basic properties of soil are presented in Table.2.

Table.2 Basic properties of soil

S. No	Tests Conducted	Result
1.	Specific Gravity	2.69
2.	**Atterberg Limits** a) Liquid limit (%) b) Plastic limit (%)	 60.00 35.00
3.	**Grain size analysis** % Gravel (> 4.75mm) % Sand (0,075mm – 4.75 mm) % Fines (< 0.075 mm)	 0 12 88
4.	Plasticity Index	25.00
5.	Free Swell Index, FSI in %	30.00
6.	**Standard Proctor Test** Optimum Moisture Content, OMC in % Maximum Dry Density, MDD in kN/m^3	 26.50 14.10

7.	Unconfined Compression Strength, UCS in kPa at OMC	245.00
8.	Un soaked CBR in % at OMC	At 2.5 mm – 4.0% At 5.0 mm – 3.5%

Fig.1(a). Clay **(b). Terrazyme** **(c) Terrazyme Mixing with pipette**

2.3 Terrazyme

Natural organic substances called bio-enzymes may disassemble complicated molecules and transform them into more manageable forms that can be utilised by plants and other creatures. When used in soil stabilization, bio-enzymes can help improve the soil's structure, increase its water-holding capacity, and enhance its nutrient content, among other benefits. In building and engineering projects, the usage of bio-enzymes and marble dust can offer a reliable and long-lasting solution for soil stabilisation. This strategy not only lessens environmental contamination but also offers a practical and environmentally friendly substitute for traditional soil stabilisation techniques. Terrazyme is a liquid that is made from vegetable extracts and is a natural bio-enzymatic soil stabiliser that is non-toxic, non-corrosive, and inflammable

Enzyme Dosage:

The enzyme dosage was varied from 200ml/1m^3 to 800ml/1m^3 i.e., 200 ml/m^3, 400 ml/m^3 and 800 ml/m^3. The sample calculation for arriving quantity of Terrazyme is presented.

Bulk Density of BC soil = 1.788 g/cc
Bulk Density = Weight / Volume
Weight = Bulk Density x Volume
For Dosage 1
200 ml for 1.0 m^3 of soil = 1.788x 1.0 x 1000 = 1788 kg of soil. In 1 kg soil = 0.125 ml of Terrazyme
For Dosage 2
400 ml for 1.0 m^3 of soil = 1.788 x 1.0x 1000 =1788 kg of soil. In 1 kg soil 1 kg = 0.25 ml of Terrazyme
For Dosage 3
800 ml for 1.0 m^3 of soil = 1.788 x 1.0 x 1000 = 1788 kg of soil. In 1 kg soil = 0.5 ml of Terrazyme.
As per the above calculations, the quantity of Terrazyme dosage used is presented in Table.3.

Table.3 Enzyme Dosages

Dosages	**Per 1m^3 of soil**	**ml/kg of soil**
1	200ml	0.125
2	400ml	0.25
3	800ml	0.5

***2.4 Marble* Dust**

About 40% of waste is being generated from marble industry, while shaping the marble tiles. This waste from marble industry is known as marble dust. Marble dust, if not utilized would result in environmental pollution as well as dumping of it occupies the fertile land. One of the ways to address the issue of utilization of marble dust is soil stabilisation. Marble dust additive had a favourable impact on the brick manufacturing and it imparts required physical, chemical and mechanical properties to bricks. The marble dust was collected from stone polishing factory in Yerraguntla, Y. S. R. Kadapa District, Andhra Pradesh, India. The basic properties of marble dust are presented in Table.4.

Table.4 Test results of Marble Dust

S.No.	Engineering Property	Value
1	Specific Gravity	2.54
2	**Grain Size Analysis** Gravel (%) Coarse sand (%) Medium sand (%) Fine sand (%) % Fines (Silt and Clay)	 0.00 0.00 5.00 8.00 87.0
3	**Plasticity Characteristics** Liquid limit (%) Plastic limit (%)	 NP NP
4	**Shear strength parameters** Cohesion in kPa Angle of internal friction in Deg	 0 33.86

4.0 Results and Discussion

4.1 Atterberg Limits

Fig.2. shows the variation of Atterberg limits such as liquid limit (LL) and plastic limit (PL) and plasticity index (PI) with the varied Terrazyme proportions of 0.125ml/kg, 0.25ml/kg, 0.5ml/kg admixed to clay along with a constant proportion of 15% marble dust. From this figure, it is observed that as the percentage of Terrazyme increases there is marginal decrease in LL, PL and PI. The Liquid limit (LL) for 0% Terrazyme is 60% and further its values are 59%, 57.5% and 58% respectively for Terrazyme proportions of 0.125ml/kg, 0.25ml/kg, 0.5ml/kg. The Plastic limit for untreated clay is 37% and further these values are 35%, 33% and 31% respectively for clay soil treated with Terrazyme proportions of 0.125ml/kg, 0.25ml/kg, 0.5ml/kg. The plastic limit variation is also marginal with the increase of dosage of Terrazyme.

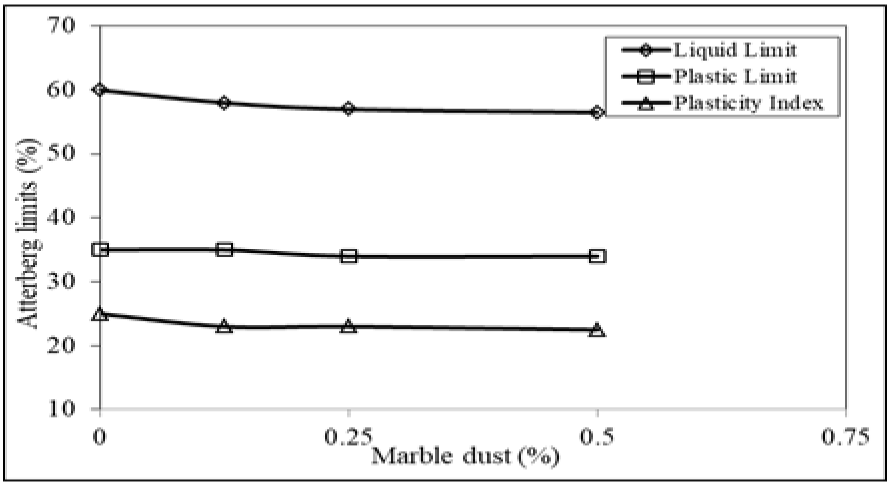


Fig.2. Variation of Atterberg limits (LL, PL and PI) with Terrazyme and 15% MD

4.2 Standard compaction test

Fig.3 shows the variation in maximum dry density (MDD) and optimum moisture content (OMC) for varied dosages of Terrazyme and 15% marble dust. With the increase in the percentage of Terrazyme, the dry density of the soil increased from 14.1 kN/m^3 to 14.9 kN/m^3 for Terrazyme dosage of 0.125ml/kg and 14.1kN/m^3 to

15.7 kN/m^3 for 0.25ml/kg dosage when compared to untreated soil.

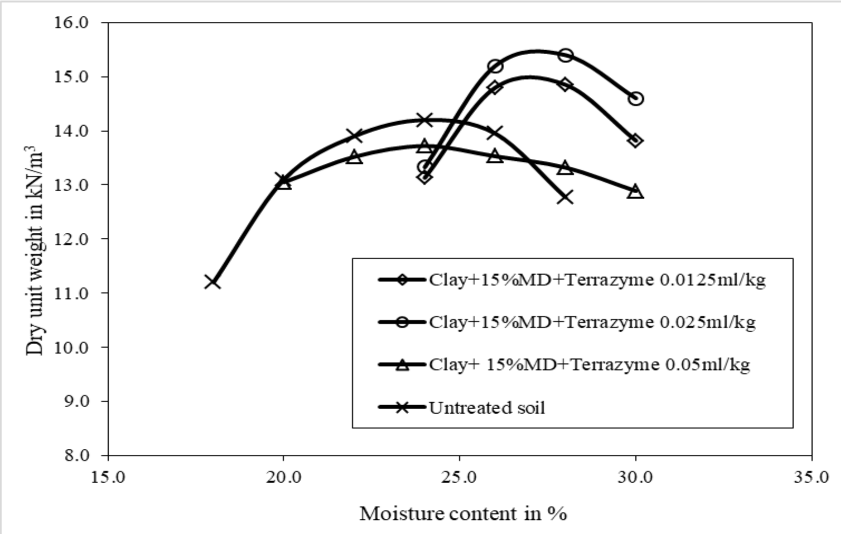


Fig.3. Compaction curves for untreated soil and soil treated with various dosages of Terrazyme and 15% marble dust.

It can be further observed that the OMC has increased with the increased dosage of Terrazyme. But, at higher dosages of Terrazyme, there is decrease in OMC and is close to the OMC of untreated soil. At 0.25ml/kg dosage of Terrazyme there is improvement in MDD and its value is 15.8 kN/m^3.

4.3 Unconfined Compression Strength (UCS)

UCS test is performed to understand the strength gain of the soil sample with the increased dosage of Terrazyme. The test was conducted as per the procedure recommendation in IS: 2720-Part 10-1991. Fig.4 presents the variation in compression stress with the axial strain of soil treated with Terrazyme and 15% marble dust and subjected to curing period of 7 days. As the strain increases, the compression stress is increasing gradually up to certain strain level and thereafter, further increase in strain causing failure in the soil samples which are treated with Terrazyme and 15% marble dust. From the figure, it is observed that even though 0.5ml/kg Terrazyme added soil has highest strength, it showed peak and fell down drastically. It can be attributed that the higher dosage of Terrazyme causes brittle nature to the soil. The soil sample which is treated with 0.25ml/kg Terrazyme, showed slow reduction in compression stress even after achieving the peak. It indicates that the soil cannot undergo drastic failure even after reaching the failure load.

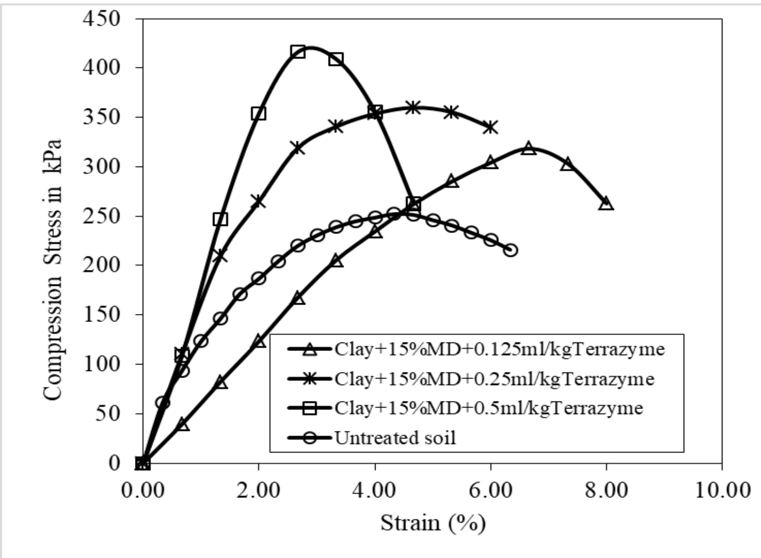


Fig.4. Variation of compression stress with axial strain for Terrazyme +15% marble dust treated clay soil and cured for 7 days

Fig.5 presents the variation in compression strength of treated clay soil and subjected to 14 days curing. From this figure, typically it is observed that there is an improvement in the strength compared to the 7 days cured samples. Also, the higher compression strength is observed corresponding to the Terrazyme dosage of 0.25 ml/kg. Similar such trend is further observed for the samples tested after the curing period of 28 days and is shown in Fig.6. With the increase in curing period, it is observed that there is an increase in the failure strain and also improvement in the strength. The addition of Terrazyme to clay soil and further subjecting the samples to curing are resulting ductile behaviour to the soil. In all the proportions of Terrazyme, the dosage 0.25 ml/kg resulted higher strength to the soil.

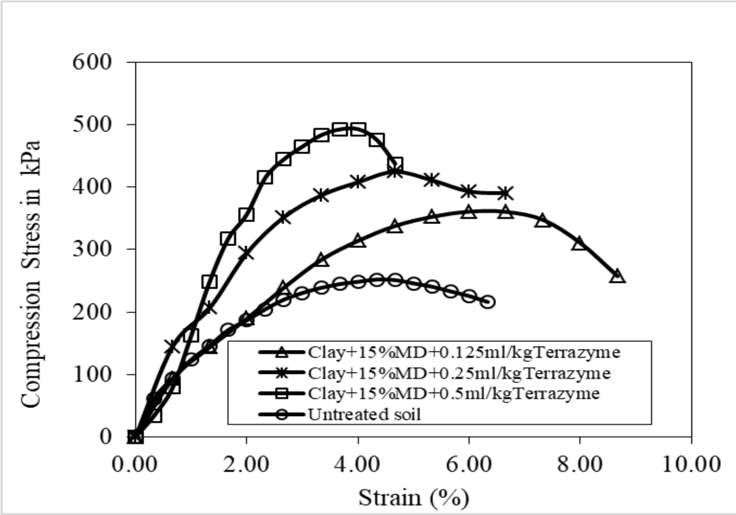


Fig.5. Variation of compression stress with axial strain for Terrazyme +15% marble dust treated clay soil and cured for 14 days

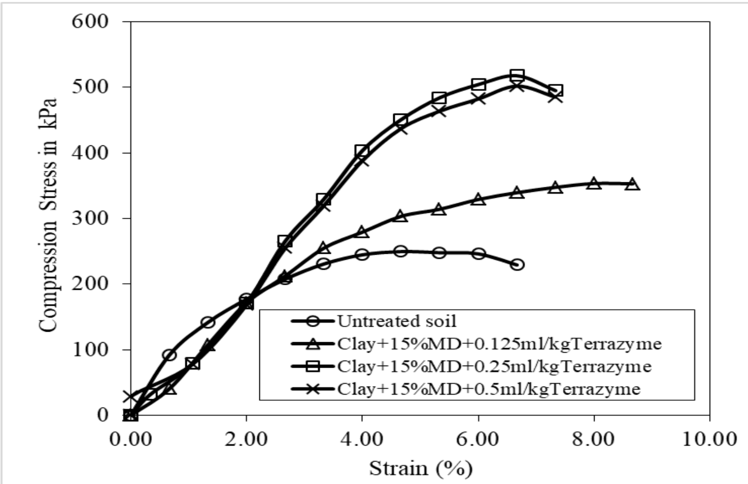


Fig.6. Variation of compression stress with axial strain for Terrazyme +15% marble dust treated clay soil and cured for 28 days

Unconfined compressive strength of treated and cured soil samples is presented in Fig.7. It is noticed that as the Terrazyme dosage increases the strength is increasing with the curing period. In all the dosages, it is further observed that 0.25ml/kg is showing higher strength comparatively. The samples treated with 0.25ml/kg and cured for 28 days showed 100% improvement in the UCS compared to the untreated soil. Similarly, the soil sample treated with 0.50ml/kg dosage of Terrazyme and cured for 28 days showed almost same strength. It means that the possible reactions would have happened within 14 days of curing in relation to strength improvement.

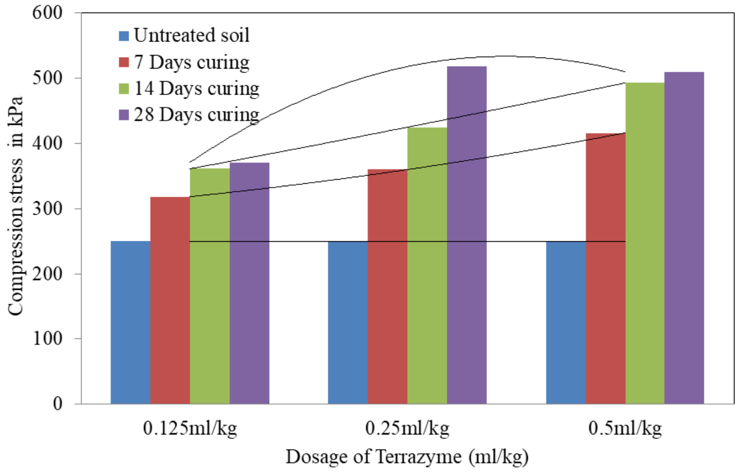


Fig.7. Variation of UCS of soil samples treated with Terrazyme+15% marble dust and also subjected to curing period 7, 14 and 28 days.

California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) test was performed as per recommendation of IS code: 2720 part 16 1987 to evaluate the strength of soil subgrades and base course materials. CBR test is performed on compacted soil samples treated with various dosages of Terrazyme and 15% Marble dust. The treated and compacted soil samples were subjected to curing in the CBR mould in a controlled condition for 7, 14 and 28 days and were tested for load – penetration response. The load-penetration curves for Terrazyme treated soils, which are subjected to curing period of 7, 14 and 28 days are presented in Figs. 8 to 10. From these figures, it is observed that as the curing period increases, the load response against to the penetration is increasing. It is further observed that with the increased dosages of Terrazyme, there is an increase in resistance against to the penetration of plunger.

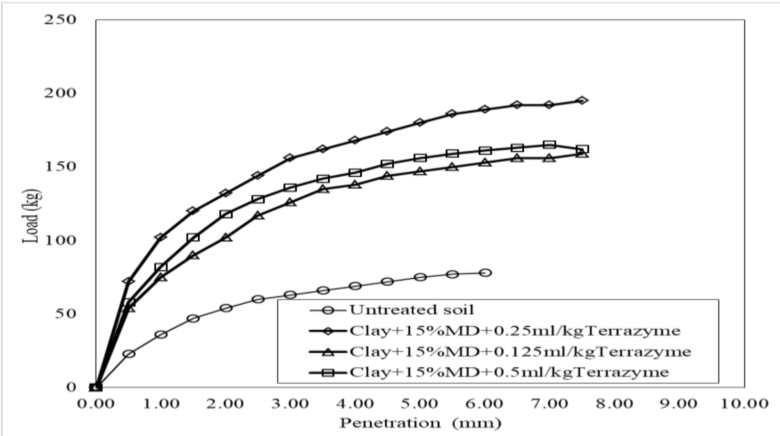


Fig.8. Load versus penetration curves of Terrazyme treated soil samples and cured for 7 days

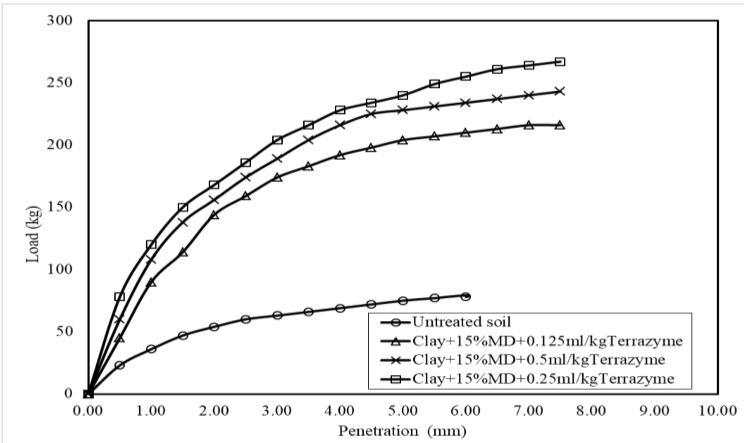


Fig.9. Load versus penetration curves of Terrazyme treated soil samples and cured for 14 days

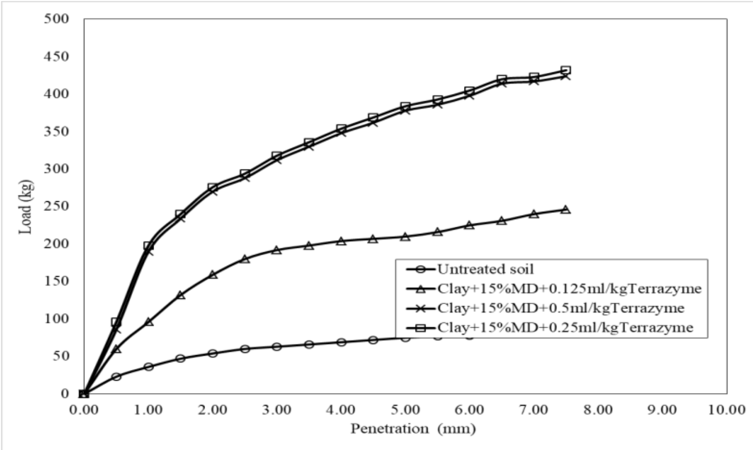


Fig.10. Load versus penetration curves of Terrazyme treated soil samples and cured for 28 days

The California Bearing Ratio (CBR) values are calculated from the above figures corresponding to 2.5mm, 5.0mm and 7.5mm. The CBR values obtained are presented in Table.5. From this table, it is observed that at 2.5mm penetration, the CBR values are higher for all the samples as compared to the other penetrations. The CBR values obtained corresponding to 5mm and 7.5mm are almost similar without much variation. Further it is observed that as the curing period increases, the CBR is improving and for higher curing periods, it is showing similar range. Also, noticed that as the dosage of Terrazyme increases, there is an increase in CBR and this increase is drastic as compared to the untreated soil. At higher dosages of Terrazyme such as 0.25ml/kg and 0.5ml/kg, the variation n CBR is found negligible. Based on the strength and CBR variations, it is observed that the dosage of Terrazyme 0.25ml/kg is optimum in improving the clay soil for pavement construction.

Table 5: CBR values for all dosages after 7, 14, 28 days desiccator dried curing

Curing period	Dosage (ml/kg)	CBR values		
		Penetration@ 2.5mm	Penetration@ 5mm	Penetration@ 7.5mm
07 Days	0.125	8.54	7.153	7.373
	0.25	10.51	8.75	9.48
	0.5	12.701	11.095	11.825
14 Days	0.125	9.343	7.591	7.883
	0.25	13.51	11.67	13.00
	0.5	14.453	12.555	13.285
28 Days	0.125	13.139	10.219	12.00
	0.25	21.46	18.686	21.02
	0.5	21.00	18.1	20.6

3.0 Material Characterization

3.1 X-Ray Diffraction (XRD)

X-ray diffraction (XRD) was performed to notice the mineralogical changes in the soil samples treated with Terrazyme and Marble dust also to see the growth in cementation in treated soil.

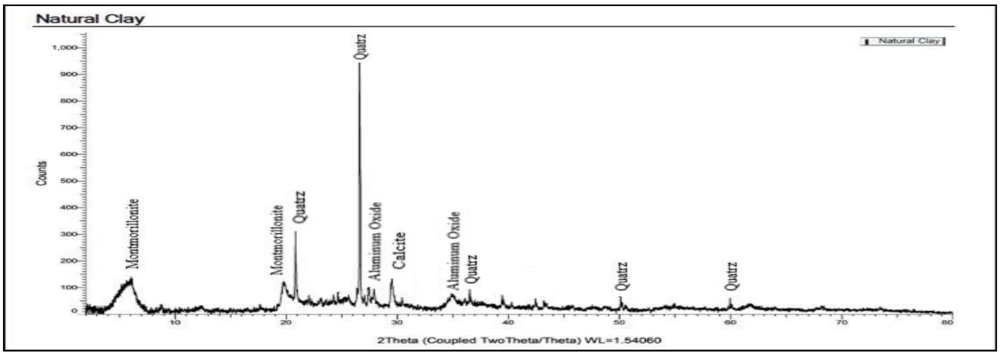


Fig.11. XRD pattern of untreated clay.

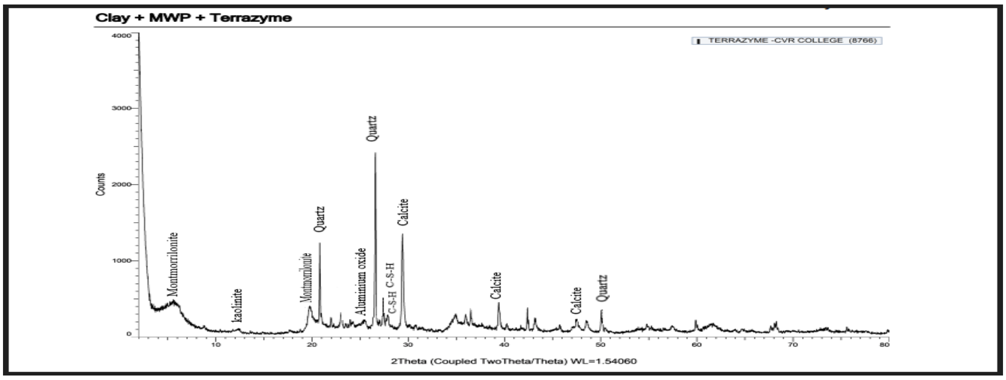
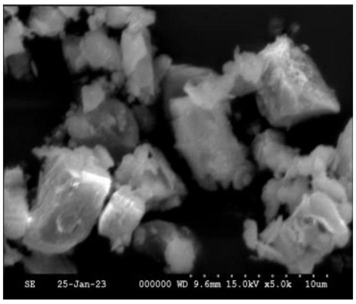


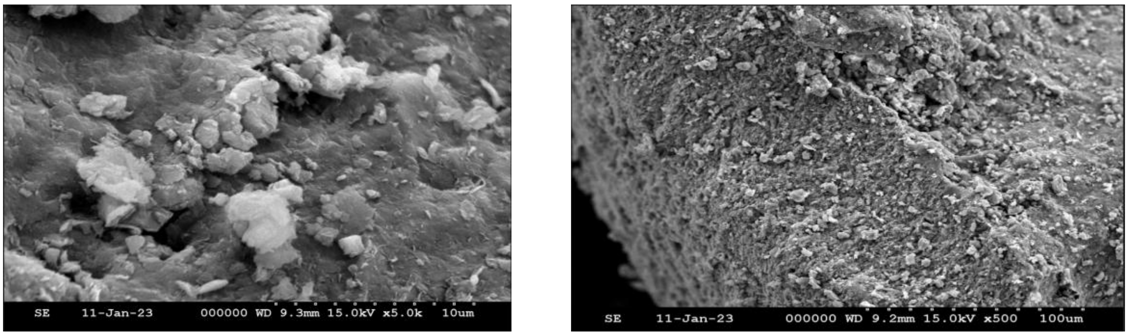
Fig.12. XRD pattern of clay stabilized with 15% marble dust and Terrazyme dosage of 0.25ml/kg and subjected to 28days curing

From the peaks present in Figs.11 and 12, it is observed that there are traces of quartz in both untreated and treated clay soil. Additionally, the treated clay has active minerals such as muscovite, kaolinite, alumina, and calcite. Further, the treated clay soil resulted in formation of new minerals like Calcium – Silicate - Hydrate (C-S-H) that would impart the strength to the clay soil. The increase in unconfined compressive strength of stabilised soil is attributed to formation of calcium silicate hydrate (C-S-H) gel after hydration. Addition of marble powder resulted in decrease of amount of montmorillonite in the clay soil, in turn; the swelling behaviour of clay would further be controlled.

3.2 Scanning Electron Microscope (SEM) Analysis

The images obtained from Scanning Electron Microsope are presented in Figs.13 to 15. Fig.13 is the SEM image of clay soil at 5000 magnification and 500 magnification. Fig.14 shows the SEM images of marble dust at 10000, 5000 and 1000 magnification. Fig.15 shows the images of clay soil stabilized with 0.25ml/kg Terrazyme + 15% marble dust and sampl cured for 28 days. From the clay soil images, it is observed that there is montmorillonite mineral and also chemical compounds like calcite and aluminium oxide in clay soil.

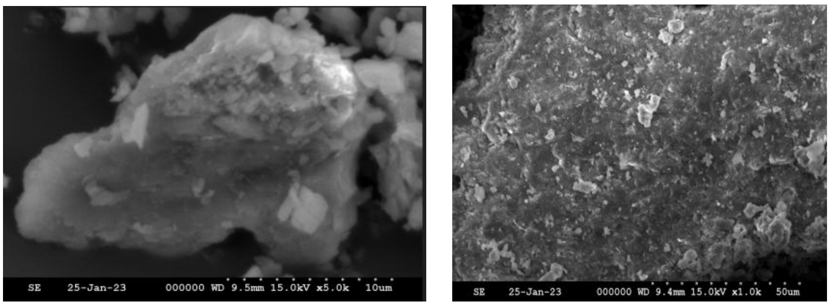




(a) (b)

Fig.13. SEM images of clay soil a) clay at x5000 manigication and b) clay at x500 magnification

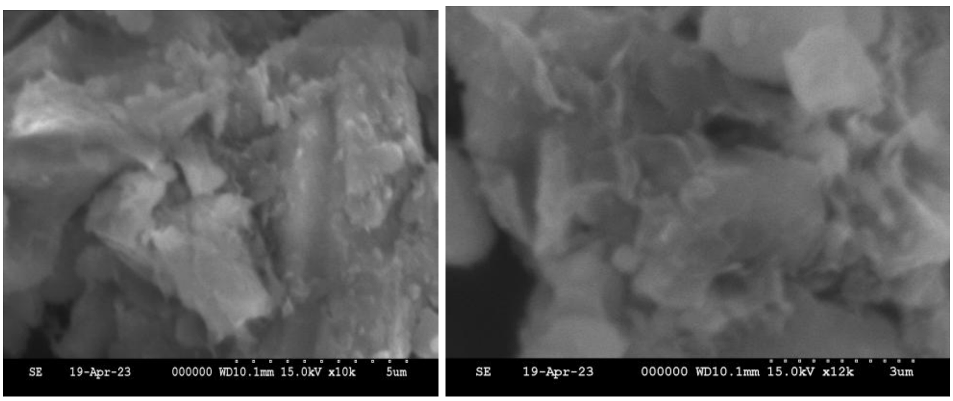
From the marble dust images, it is observed that there are kaolinite, calcite and quartz in the marble dust used in the study.



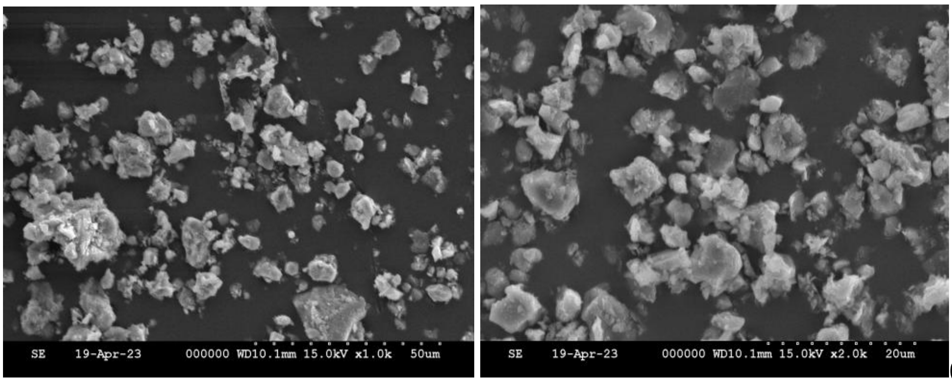
(a) (b)

Fig.14. SEM images of marble dust a) MD x10000 magnification and b) MD at x5000 magnification and c) MD at x1000 magnification.

The Terrazyme treated soil samples cured for 28 days showed formation of calcium-silicate-hydrate (C-S-H) gel and it can be evidenced in the SEM image shown in Fig.15. These images are taken at magnification of 5000, 10000, 12000, 1000 and 2000. Due to the associated reactions happened in treated soil, it resulted in formation of kaolinite and muscovite minerals. It is clear that there is cementation between the particles and also reduction in concentration of montmorillonite mineral. The chemical reactions happening are presented below.



(a) (b)



(c) (d)

Fig.15. SEM images of clay stabilized with 15% MD and 0.25ml/kg Terrazyme dosage after 28 days of curing period. a) x5000 magnification b) x10000 magnification c) x12000 magnification d) x1000 magnification and e) x2000 magnification.

Montmorillonite:

$2CaCO_3 + 4SiO_2 + 4H_2O + Al_2O_3 + MgO \rightarrow Ca_2SiO_4 + 2Mg(OH)_2 + 2CO_2 + Al_2Si_2O_5(OH)_4$

Kaolinite:

$CaCO_3 + 2SiO_2 + 2H_2O + Al_2O_3 \rightarrow CaSiO_3 + 2H_2CO_3 + Al_2Si_2O_5(OH)_4$

In both the cases, the reaction involves the dissolution of calcite ($CaCO_3$) and the reaction of its ions with the silica (SiO_2) and Aluminum (Al_2O_3) present in the clay mineral. This forms the calcium silicate hydrates ($CaSiO_3$ and Ca_2SiO_4) and Aluminum silicate hydrates ($Al_2Si_2O_5(OH)_4$)), which together form the C-S-H gel. The magnesium hydroxide ($Mg(OH)_2$) produced in the reaction with montmorillonite may also contribute to the formation of the C-S-H gel. The carbon dioxide (CO_2) produced in both reactions is released a as gas.

5. Conclusions

The maximum dry density (MDD) for soil treated with 0.25ml/kg Terrazyme and 15% marble dust is increased about 12% than untreated soil and the Optimum moisture content (OMC) remains unchanged. Liquid limit of soil treated with 0.25ml/kg Terrazyme and 15% marble dust is reduced 5% and plastic limit reduced 11% compared to untreated soil. The unconfined compressive strength (UCS) of untreated clay is 245 kPa which is increased about 44%, 111%, and 103% by adding the Terrazyme dosages of 0.125ml/kg, 0.25ml/kg and 0.5ml/kg and cured for 28days. From the SEM images of clay soil and clay soil admixed with Terrazyme, it can be observed that the Terrazyme which is added to clay soil acts as a catalyst in accelerating the cementation. Calcium-Silicate-Hydrate is formed from the reaction of Marble dust with untreated soil. CBR test results shows the increase in percentage of CBR is more for dosage of Terrazyme 0.25ml/kg compared to 0.125ml/kg and 0.5m/kg. CBR of untreated clay at 5mm penetration is 4%, whereas the CBR values of clay soil treated with 0.125 ml/kg, 0.25ml/kg and 0.5 ml/kg and cured for 28 days showed 13.13%, 21.46%, and 21.00% improvement as compared to the untreated soil. It is witnessed that mixing of 0.25ml/kg of Terrazyme along with 15% marble dust provides improved strength and CBR of the soil subgrade.

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