Cationic Catalysis of Lime Treated Soft Soils

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Abstract: Stabilization of soils is an effective method for improvement of soil properties and the pavement system performance. A study was conducted to examine the stabilizing effects of an enzyme and lime on improving the suitability of a natural soft clay as a subgrade material. The tests were carried out by introducing the additives into the soil in two different stages. The enzyme and lime were first mixed individually- Soil Lime mixtures and Soil Enzyme mixtures and later concurrently- Soil Enzymatic Lime mixtures. The initial part of the study determined the variation of index properties of the three soil combination. Laboratory tests were performed with different percentages of the additives on the soil and the modification of Atterberg Limits, Grain Sizes Distribution and Free Swell Index in the soil mixtures was studied week after week for a month. From the result of the plasticity indexes obtained, satisfactory values were noted and the respective dosages were chosen as the optimum. The latter part of the study examined the optimum dosages of enzyme, lime and enzymatic-lime that produced maximum strength improvement on the treated soil. The strength criteria were investigated by conducting unconfined compressive tests on 3.8mm diameter cylindrical specimens of samples cured with the dosages at and near the optimum combinations. The effect of density and moisture content was predominant in all cases and this enabled to identify the maximum dry density (MDD) and optimum moisture content (OMC) for the mixes. It was found that enzymatic-lime stabilized soils gave speedy stabilization as compared to enzyme stabilized and lime stabilized soils. The paper discusses the results obtained throughout the study. Under standard conditions, satisfactory reasons are found stating that Enzymatic Lime is a possible economical and innovative methodology for soil stabilization.

Keywords: Ground Improvement, Enzyme, Lime Stabilization, Soft Soil.

Introduction

In situ soil stabilization is commonly brought about by compaction, rearrangement of soil particles, addition of chemical reactants, or thermal process. Among these techniques, hydrated lime has proved to be a cost effective, easy to apply, favored method of soft soil improvement for most engineers. Rooted in the success of lime stabilized soils, various additives have been suggested to be incorporated with soil and with soil-lime and tried over the last few decades. Numerous research works are and have been done to understand the behavior of soil-lime mixtures in the presence of other salts/chemicals. But the effect of various inorganic additives such as calcium chloride and calcium sulphate with lime on the behavior of clay is yet to be studied in detail. Based on this idea, it was decided to integrate an enzyme into soils along with hydrated lime. The enzyme used in the work is an enzyme soil stabilizer produced in the United States by Nature Plus, Inc. A number of case studies have been reported [1] stating that enzyme by itself improves soil properties while no literature has been found on enzymatic lime soil stabilization. It is to be assumed in the work that like soils subjected to other modes of treatment, any improvements in the engineering behavior of enzymatic lime treated soil systems will mainly be attributed to the aggregation effects [2]The scope of the paper includes observation of the changes in Atterberg Limits of lime and enzyme treated soil systems and the unconfined compressive strength improvement of soil samples subjected to such treatments.

Mechanism of stabilization

As mentioned, the paper describes the use and effect of chemical agents lime and enzyme on the index properties of stabilized soils. The utilization of lime in soil modification is not a novel technology. It is a traditional means in a variety of construction applications since the time of Romans and has never entirely disappeared. When used in soil, lime modification describes an increase in strength brought by cation exchange capacity rather than cementing effect brought by pozzolanic reaction [3]. It alters the clay surface mineralogy, producing a reduction in plasticity and moisture holding capacity, and an improvement in soil stability. But the disadvantages of lime stabilization include lime carbonation and sulfate salt reactions which may lead to disintegration of bonds on aging. To account for the negative impacts, a number of salts and chemicals have been added with lime to soil and tested. Among these already tried and proved agents include cement, flyash, rice husk etc.

It was hence decided to mix an enzyme with lime for the purpose of soil stabilization and to study its effects on soil properties. Enzymes are organic molecules that catalyze very specific chemical reactions if conditions are conducive to the reaction. They are typically used in low concentrations as they are not consumed by the reactions they make possible. Enzyme additives attach with large organic molecules that are attracted to the clay mineral's net negative surface charge [4] Enzyme used in the work like other enzymes is costly and a method to reduce the amount of enzyme, while obtaining the same degree of improvement, if achievable, would be greatly advantageous. And since lime and enzyme use the same mechanism of cation exchange to improve soil properties, the idea to add both lime and enzyme together in the soil and to investigate the alterations in soil properties seemed feasible. On addition of both lime and TerraZyme to soil, from laboratory tests it was observed that a higher degree of strength improvement was achieved by this method. The soils achieved maximum property enhancement in two weeks or less as compared to four/six weeks in other ground improvement techniques.

Materials used and methodology

The materials used in the work are, natural clay soil organized from Pantheerancavu at Calicut, lime purchased from local market in Kunnamagalam at Calicut and enzyme TerraZyme acquired from Avijeet agencies, Chennai. The soil and enzyme have been characterized and their properties are given in Tables 1 and 2.

The soil used in the work is montmorillionitic soft clay. High percentage of montomorillonite in soils renders high degree of expansiveness. When used as a subgrade material, these soils may cause the pavements to crack without any warning . Soil stabilization by the alteration of one or more soil properties, by mechanical or chemical means, to create an improved soil material possessing the desired engineering properties [5] is the sole remedy in such cases.

The key to success in soil stabilization is soil testing. All the specimens tested in this study were prepared and tested using standard procedures described in the Bureau of Indian Standards. Soil sample was air dried for a week, pulverized manually using weights, sieved through 425 micron sieve and preserved in large open containers in an enclosed room. Lime was sieved using 425 micron sieve and preserved in an air tight container to prevent carbonation. TerraZyme was preserved in an airtight bottle in its original liquid form. Soil and lime were mixed from 0%-10%.

The consequence of lime on the plasticity of clay soils is observed more or less instantaneous. In other words, the plasticity is reduced (this is brought by an increase in the plastic limit and reduction in the liquid limit of the soil), as is the potential for volume change. [6]Hence the variations in LL and OMC were observed for each fraction within 24 hours. The minimum amount of lime that did not further reduce the LL was chosen as optimum Lime content (OLC). The OMC increased by about 5% by OLC and later remained constant. The minimum lime required to initiate soil modification was 0.5 and OLC was 3%. However soil specimens were cast in UCS moulds (3.6mm diameter and 7.8mm height) with 1,2,3,5,7 % lime at their respective OMC and cured up to four weeks in airtight bags kept in an artificial desiccator. At least six samples of the same mix type were tested and the average of the values were recorded. The variations in Liquid Limit (LL), Plastic Limit (PL), Shrinkage Limit (SL), Unconfined Compressive Strength (UCS), Free Swell Index (FSI) and particle sizes were observed. From the results the OLC was once again inferred as 3%.

Table 1. Engineering Properties of Soil

Property	Value
Liquid Limit (%)	79
Plastic Limit (%)	48
Shrinkage Limit (%)	27
Bulk Density (kN/m^3)	13.25
Max. Dry Density (kN/m^3)	17.46
Optimum Moisture Content (%)	32

Property	Value
Soil Type:	Montmorillitic
Unconfined Compressive Strength (kPa)	64
Clay content (%)	22.17
Co-efficient of Curvature, Cc	1.053
Co-efficient of Uniformity, Cu	8.16

Table 2. Properties of TerraZyme

Property	Value
Boiling Point	212 F
pH	2.8 – 3.5
Vapor Pressure (mmHg)	As Water
Melting Point	Liquid
Vapor Density (Air = 1):	1
Solubility in Water	Infinite

Property	Value
Evaporation Rate	As Water
Specific Gravity (H_2O = 1)	1.00—1.10
Appearance and Odor	Lt. Gold Liquid, Characteristic Odor

Other parameters could also have been the objective of investigation. But this paper is only relates to observation of index properties and UCS tests. Similar tests were also done to determine the optimum TerraZyme content of soil. A dilution ratio chart was provided by Avijeet agencies that calculated the optimum TerraZyme content (OEC) for a particular soil based on particle size and plasticity index. Two soils were mixed with TerraZyme, the original soil used in the research work (Soil-A) and another montmorillitic soil obtained from Quilandy (Soil-B), which had similar properties as the former. Both soils showed significant improvement in strength.

The OEC was found to be same as that computed from the dilution ratio chart. The chart was thus validated. The OEC for soil used in research was obtained as 80ml/m^3. There was no variation in OMC on addition of TerraZyme to the soil. Soil was mixed at OMC itself for all curing tests. Various combinations of soil+lime+enzyme mixtures were cast, cured and tested. The amount of TerraZyme was kept close to OEC predominantly in all cases and percentage lime was varied from 1-6%. The changes in Atterberg limits and UCS were observed within 24 hours of mixing enzymatic solutions to the soil. It was observed that the strength gain was constant or remained same when the TerraZyme content was slightly increased above 70 ml/m^3. On TerraZyme dosage above 90 ml/m^3 the strength was found to decrease drastically. Thus another set of tests were done with the new OEC and varying percentages of lime. The best combination was obtained on adding 2% lime. Further refinement tests were performed by varying lime between 1.5 and 2.5%.

Results and discussion

Soil - Lime system

Bell found that the optimum addition of lime needed for the stabilization of the soils is between 1% and 3%, while the other researchers suggested the use of lime between 2% and 8% lime by weight [6] The addition of lime results in a decrease in the liquid limit and plastic limit, a commonly observed consequence of lime addition (Sweeney et al, 1965). In the current work, the optimum lime content was found out indirectly by relying on the variation of LL values of soil, when treated with lime. The lowest LL was obtained when 3% of lime by weight was added to the soil. The OMC of soil increased by 4% at the dosage. Later air dried and pulverised, 425 micron sieved soil was mixed with lime at 1,2,3,5,7% lime at their respective OMC and cast in to cylindrical specimens in UCS moulds (3.6mm diameter and 7.8mm height) and cured up to four weeks. The specimens were tested every week for a month. Curing period significantly influenced the engineering properties of lime stabilized soil. Table 3 and figure 1 through 4 represent the respective modifications in Index Property and Unconfined Compressive Strengths. The clay contents quoted for the natural and treated soils are the percentages of particles finer than 2 micron, determined by sedimentation after pretreatment and dispersion with sodium hexametaphosphate.

Table 3. Engineering property of soil treated with various percentages of lime at four weeks

Property		Liquid Limit	Plastic Limit	Shrinkage Limit	UCC (kPa)	Free Swell Index	Silt (%)	Clay (%)
Untreated		79	48	27	90	20	23.98	22.17
Lime (%)	1	55	40	24	188	16	19	5
	2	52	37	23	202	16	18	4.9
	3	48	35	23	272	16	18.5	1.78
	5	54	38	23	192	16.5	16.1	0.726
	7	54	37	23	190	16	18	0.632

Soil mixed with low lime content attains a maximum strength in less time than that to which a higher content of lime has been added. Strength does not increase linearly with lime content and in fact excessive addition of lime reduces strength. This decrease is because lime itself has neither appreciable friction nor cohesion. The optimum lime content tends to range from 4.5% to 8%, the higher values being required for soils with higher clay fractions. [6]. On successful addition, curing and testing of soil samples with lime, the optimum lime content (OLC) for soil was verified as 3%. At this dosage the LL, PL, SL and FSI reduced to 48, 35, 23 and 16 respectively. The Plasticity Index (PI) reduced from 31 in the untreated soil to 13. The UCS value was obtained as 272kPa at the end of four weeks.

Literature reveals that reaction products formed due to soil-lime reactions show the formation of the reaction product CSH (gel) in a reticulated network (well-knit framework) which binds the individual clay particles together to form aggregations. Locat [2] reported formation of platy CASH and reticular CSH cementitious compounds in the lime-treated soil system from SEM analysis. This may be one of the reasons for the increase in UCS values of soils treated with lime.

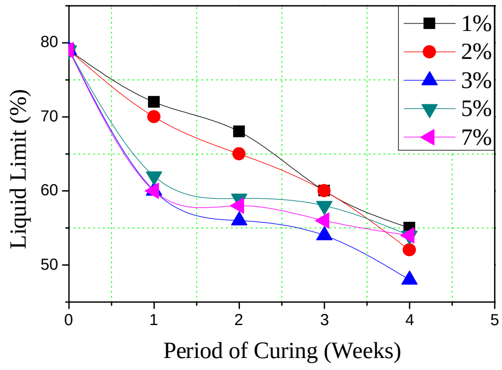

Figure 1. Variation of Liquid Limit Limits of soil treated with varying percentages of lime

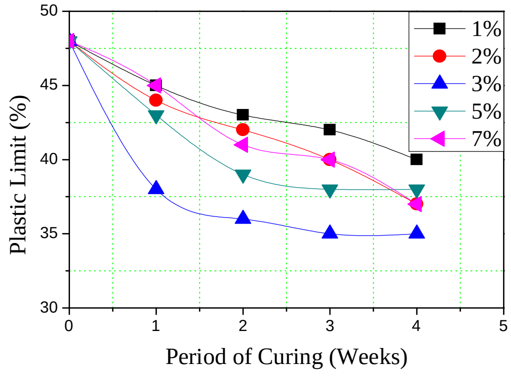

Figure 2. Variation of Plastic Limits of soil treated with with varying percentages of lime

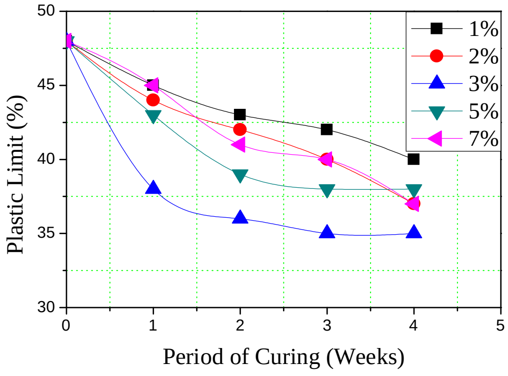

Figure 3: Variation of Effective Clay Size Particle Distribution of soil treated with with varying percentages of lime

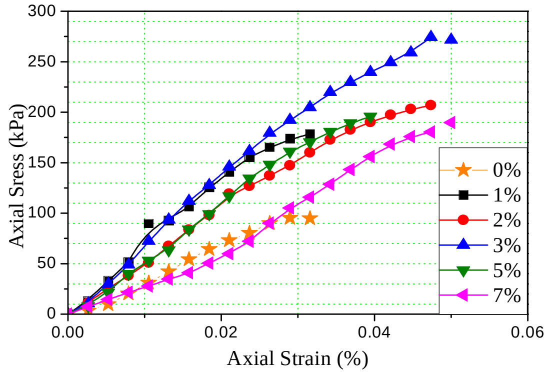

Figure 4: Stress Strain Curve of soil after 4 weeks of curing with with varying percentages of lime

Soil - Enzyme System

The dilution chart provided by NaturePlus was used to obtain an optimum enzyme dosage for soil. In order to verify the accuracy of the dilution chart, the original soil sample used in the research work (Soil-A) and another montmorillionitic soil of similar characteristics (Soil-B) were mixed with TerraZyme. The dosages chosen were 80% to 120% of the optimum dosage given by the chart. Air dried and pulverized, 425 micron sieved samples of the soil each were taken and moulded in UCS moulds (3.8mm diameter and 7.6mm height), and cured up to a month. The cured samples were subjected to unconfined compressive strength tests every week for a month. Based on the results, it was found that maximum unconfined compressive strengths was obtained for samples cast with optimum TerraZyme dosage given by chart. The samples cast with 80% and 120% optimum dosage has reduced strength with the latter percentage much lower strength values. For the next step refined TerraZyme dosages of 60 ,80, and 100 ml/m^3 were chosen, dosages near to optimum dosage. Similar to soil-lime system, air dried and pulverized, 425 micron sieved samples were mixed with the three refined TerraZyme dosages at pure soil OMC and cast in to cylindrical specimens in UCS moulds (3.6mm diameter and 7.8mm height) and cured up to four weeks. The specimens were tested every week for a month. The parameters tested were the Index Property and Unconfined Compressive Strengths.

It is observed that LL, PI and UCS alters appreciably for all stabilized soils. While during the stabilization of aggregate clay mixes with enzymes, the plasticity characteristics may fluctuate either way [7] on addition to an increase in strength characteristics. In the present study, the montmorillitic clay on reaction with TerraZyme shows decreased LL and PI. On successful addition, curing and testing of soil samples with TerraZyme, the optimum enzyme content (OEC) for soil was verified as 80 ml/m^3. At this dosage the the LL increased by 91, PL, SL and FSI reduced to 42, 17, and 16 respectively. PI increased to 49 and UCS value was obtained as 306kPa at the end of four weeks.

Dumbleton observed that cementing or aggregation of the particles of a soil will modify the effect which the clay fraction has on soil properties. On curing such a soil has reduced plasticity characteristics [8]The increase in strength and reduction in plasticity of soil on addition of TerraZyme may be due to the aggregation of soil particles. Some literature suggests formation of rough elephant skin like textural modification of soil and reduction in surface area of clay minerals, when treated with TerraZyme. Taha revealed that ESEM images for the treated and untreated samples confirmed that the treated samples appear more aggregated than the corresponding untreated sample, and the clay features are less visible [9]This cohesiveness and interlayer friction may add to the cause behind the strength increase. More detail into the mechanism of TerraZyme soil stabilization may be obtained from SEM studies, but that is beyond the scope of this paper, and is not mentioned here.

Table 4. Engineering property of soil treated with various percentages of TerraZyme at four weeks

Property		Liquid Limit	Plastic Limit	Shrinkage Limit	UCC (kPa)	Free Swell Index	Silt (%)	Clay (%)
Untreated		79	48	27	90	20	23.98	22.17
TerraZyme(ml/m^3)	70	88	43	17	182.5	16	19.5	10.2
	80	91	42	17	306.2	16	18	6.8
	90	86	42	16	135.6	16	16	6

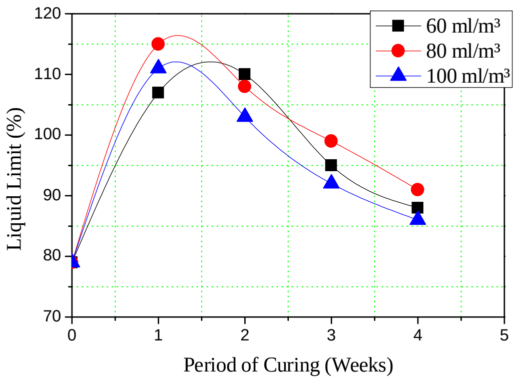

Figure 5. Variation of Liquid Limit of soil treated with with varying percentages of TerraZyme

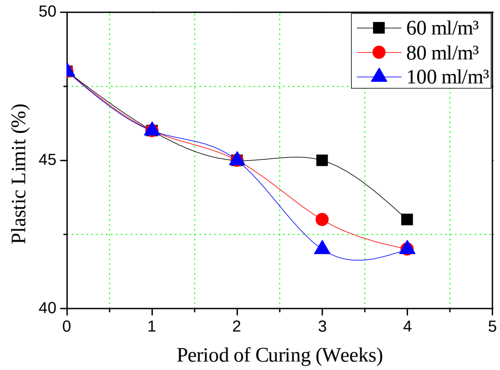

Figure 6. Variation of Plastic Limit of soil treated with with varying percentages of TerraZyme

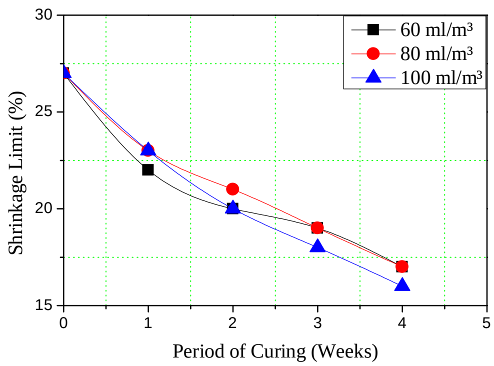

Figure 7. Variation of Effective Clay Size Particle Distribution of soil treated with with varying percentages of TerraZyme

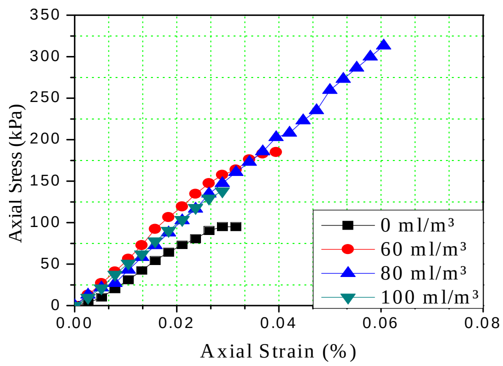

Figure 8. Stress Strain Curve of soil after 4 weeks of curing with with varying percentages of TerraZyme

Soil-Enzyme-Lime system

The results obtained in the soil-lime and soil-enzyme were positive. And it has been confirmed that both lime and TerraZyme use the mechanism of cation exchange for soil stabilization. Hence varying percentages of lime and enzyme were mixed together and tested. Variation in the values of Atterberg Limits and UCS in the first 24 hours were regarded to understand the consequence of enzymatic lime system in the soil. The effect of TerraZyme was limited when dosage was increases above 70 ml/m^3 in the presence of lime. Thus further tests were done with the new OEC as 70 ml/m^3 and varying percentages of lime from 1 and 5%. Air dried and pulverized, 425 micron sieved samples were mixed with the new OEC, and various lime percentages at pure soil OMC and cast in to cylindrical specimens in UCS moulds (3.6mm diameter and 7.8mm height) and cured up to four weeks. The specimens were tested every week for a month. Based on the values of UCS, lime percentages were further refined to be between 1.5 and 2.5 %.

Table 5. Engineering property of soil treated with various percentages of enzymatic Lime at four weeks

Property		Liquid Limit	Plastic Limit	Shrinkage Limit	UCC (kPa)	Free Swell Index	Silt (%)	Clay (%)
Untreated		79	48	27	90	20	23.98	22.17
Optimum TZ and Varying % Lime	1.5	88	43	17	182.5	16	19.5	10.2
	1.75	91	42	17	318.2	16	18	6.8
	2	86	42	16	135.6	16	16	6

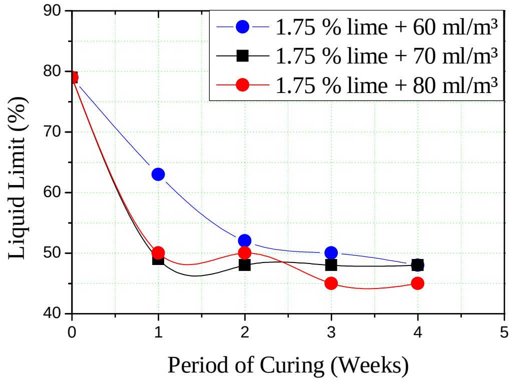

Figure 9. Variation of Liquid Limit of soil treated with with varying percentages of enzymatic lime

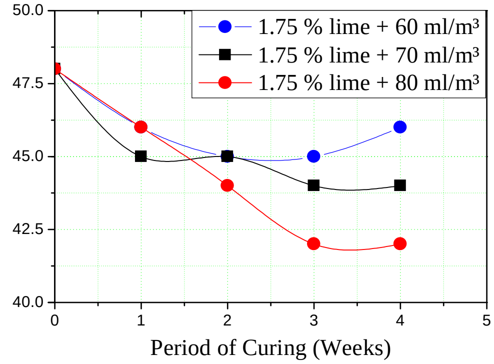

Figure 10. Variation of Plastic Limit of soil treated with varying percentages of enzymaticlime

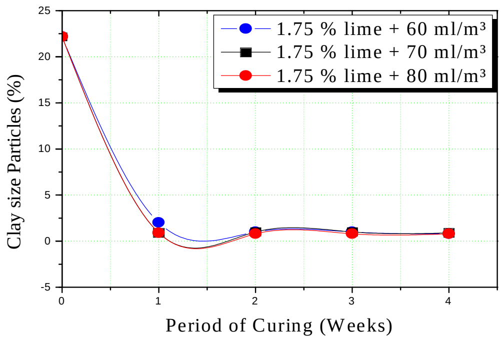

Figure 11. Variation of Effective Clay Size Particle Distribution of Soil treated with varying percentages of enzymatic lime

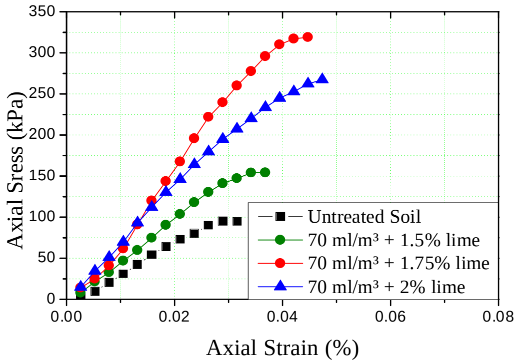

Figure 12. Stress Strain Curve of soil after 4 weeks of curing with varying percentages of enzymatic lime

The parameters tested were the Index Property and Unconfined Compressive Strengths in this step. The end result verified that 1.75% lime presented optimal improvement. Thus final optimal mix was obtained as 70ml/m^3 of TZ On successful addition, curing and testing of soil samples with enzymatic lime, the optimum additive content (OLT) for soil was verified as 70 ml/m^3 of TerraZyme and 1.75% of lime. At this dosage the the LL, PL, SL and FSI reduced to 44, 40 18 and 17 respectively. PI decreased to 4 and an UCS upto 300 kPa was achieved in the 2nd week itself. The rate of strength gain was however slow after the 2nd week and reached only 330 kPa at the end of 4th week.

It can be observed from the graphs that when soil is treated with enzymatic lime, the strength increase is predominant in the first two weeks and slower afterwards. The value of UCS obtained in two weeks on treatment with enzymatic lime is higher than the strength obtained at the end of four weeks on treatment with lime and enzyme. The plasticity characteristics are marginally affected much when lime and enzyme are added together to the soil as compared to individual agent stabilizations. In short the new system speeds up the stabilization of soils and reduces the curing and construction time radically.

Decrease in clay content – GSD

From figures 3, 7 and 11, it is observed that stabilization of soils bring about an apparent decrease in the percentage of clay particles in soil. This is mainly due to the agglomeration effect of stabilizers. When the clay contents are measured by sedimentation, visual and microscopic examinations reveal that several undispersed particles remain as a result of persistent aggregation. Hence when the results give low clay content, the actual mineral contents are in fact higher. In such cases low values of liquid and plastic limit are observed in relation to large values of actual clay mineral content [8]. Usually a relation between soil properties and clay content may be correlated. But this is impossible for treated soils, due to the drastic disparity in their nature and cannot be applied for the case mentioned in this paper. The other factors affecting the same may be understood only on a detailed examination of the treated soils and a fuller understanding of the origin of the soil materials, but that is again outside the scope of the paper.

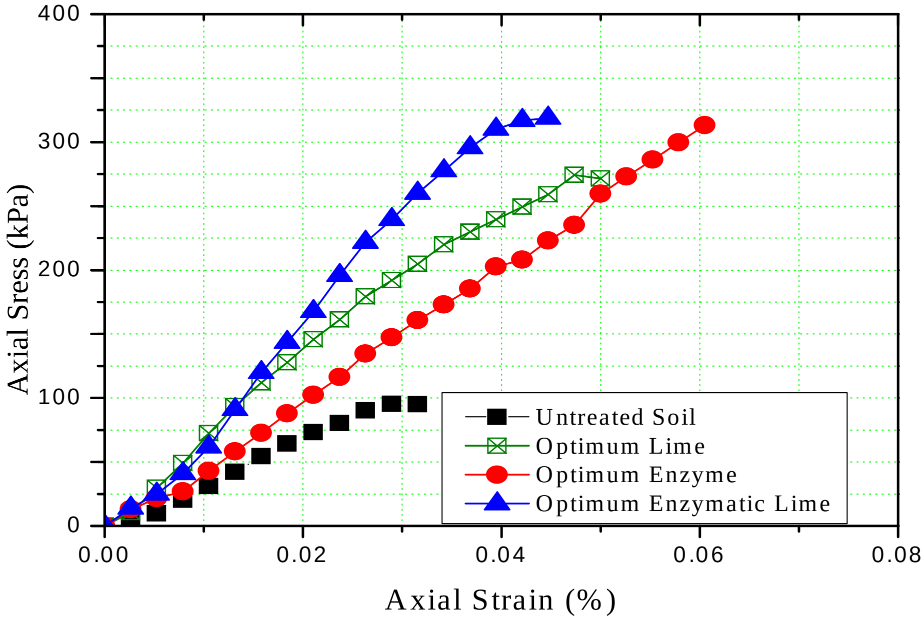

Figure 13. Stress Strain Curve of soil after 4 weeks of curing with OLC, OEC and OLT

Conclusion

Both lime and TerraZyme are independently used extensively for subgrade stabilization. The technique of introducing enzymatic lime into soil is a novice procedure which indicates to impart better and quicker stabilization from the laboratory studies conducted in the work. The result is the transformation of soil into a stronger permanent soil matrix in half the time as that required by lime or TerraZyme alone. Lower plasticity index indicates reduced swelling and shrinking, an adaptation that will alleviate common problems in roadways. By improving the quality of roads, the travel along unpaved roads maybe assured pleasant as well. The practice may be consequently integrated into stabilization of soils for subgrade.

The nature of enzymatic lime stabilized soils has not been studied as on date. Hence the behavior presented in this work may differ when applied to other soils under the same conditions. Enzymes catalyze very specific chemical reactions. As such, it is difficult to discern a general stabilization mechanism due to variations in the soil-specific reactions [10]. Montmorilliic clay on application of enzymatic lime showed decreased plasticity characteristics with improved strength. The catalystic action of TerraZyme appears to have increased in the presence of lime. A higher degree of stabilization has occurred with shorter curing period. Therefore a possibility of accomplishing soft soil stabilization has been recognized. The points to be noted include:

1. An increased aging effect on enzymatic lime stabilized soils has not been studied.
2. The improvement in strength may be attributed to the compaction effect and may vary in field conditions
3. Salts present in field conditions may affect the catalystic nature of enzymes, and cannot be predicted now
4. The proposed stabilization technique is not authenticated, but literature tends to support the same. In general clayey soils may be assumed to respond positively to this system

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