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LIME LEACHABILITY STUDIES ON STABILIZED EXPANSIVE SEMI-ARID SOIL

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ABSTRACT: The present study is aimed at examining the role of lime and the nature of leaching solution on the lime leaching characteristics of an expansive soil originating from the Kingdom of Saudi Arabia. Lime leachability studies were carried out in specially fabricated molds subjected to continuous leaching conditions. The specimens were compacted directly into specially fabricated perspex molds and cured for 7, 14 and 28 days under constant humidity conditions. In order to study the rate at which the calcium ions leach out from the lime treated clay matrix, water (leaching solution) was allowed to flow through the compacted specimen continuously for seven days and the resultant calcium concentration in the leachate was determined. The effects of various parameters like lime content, curing period and the pH of leaching solution on the lime leachability values has been studied. It is observed that, at a given lime content, the calcium concentration in the leachate reduces with curing period. Relatively higher amounts of lime leached under acidic conditions and the flow period does not affect the lime leaching patterns.

Keywords: Expansive soil, Cementitious Compounds, Landfill, Lime, Lime leachability, Mineralogy.

1. INTRODUCTION

The expansive soils with their innate potential in exhibiting detrimental volume changes at different moisture conditions have been a cause of concern globally [1-2]. Major corrective measures to circumvent the problems posed by these soils include preloading [3], chemical treatment [4] and the use of cohesive non-swelling soil (CNS) cushion [5]. Lime is by far the most widely used chemical additive for the treatment of expansive soils. It has been proven suitable for clays or silty clays. In most of the applications such as structural fills, liners and landfill covers, road bases, and embankments etc., lime treated soils are often prone to the leaching of lime, which will reduce the lime content from the stabilized clay matrix affecting their performance [6]. Further, the lime leaching from the clay matrix severely hampers the rate at which pozzolanic reactions proceed, resulting in the increased material porosity as well as hydraulic conductivity and reduced mechanical properties. Hence, the durability of lime treated soils depends on the leachability of lime from the matrix. In this article, lime leachability studies on Al-Ghat soil, stabilized with lime have been conducted. The effects of various parameters like lime content, curing period and the pH of leaching solution on the lime leachability values have been studied. The mechanism with which the lime retention is achieved has also been brought out.

2. MATERIALS

2.1 Soil

The tests were conducted on cohesive soil collected from Al-Ghat town, located 270 km to the Northwest of Riyadh (26° 32' 42" N, 43° 45' 42" E). Sampling was carried out at a depth of 3 m. The physical properties and chemical composition are reported in Tables 1 and 2 respectively. It has been classified as a high plasticity clay, as per unified soil classification system. The degree of expansivity was established based on measured modified free swell index (MFSI) values measured by means of sediment volume in carbon tetra chloride. For Al-Ghat the MFSI value was less than 1.5 cm^3/g.

Table 1 Physical properties of the soil

Physical Property	Al - Ghat
Liquid Limit (%)	62
Plastic Limit (%)	30
Shrinkage Limit (%)	17
Plasticity Index (%)	32
Linear Shrinkage (%)	31
% Finer than 200 μm	87.3
USCS Classification	CH

**'USCS' refers to unified soil classification system; 'CH' refers to clay with high plasticity.*

Table 2 Chemical composition of the soil

Chemical Composition (%)	Al - Ghat
K^+	1.1
K_2O	1.3
Al	7
Al_2O_3	13.3
Si	9.8
SiO_2	21
Ca^{+2}	1.4
CaO	2

The predominant minerals present in the soil were determined by carrying out XRD using Bruker D8 Advance system. Sample was scanned from 2° to 60° (2θ) using 2.2kw cu anode long fine focus ceramic x-ray tube at a scanning rate of 1 degree per minute. Fig. 1 depicts comprehensive X-Ray Diffraction analysis. Apart from quartz, the predominant minerals include Kaolinite, Endelite, Dickite, Calcium sulfate hydrate and Calcium aluminium silicate.

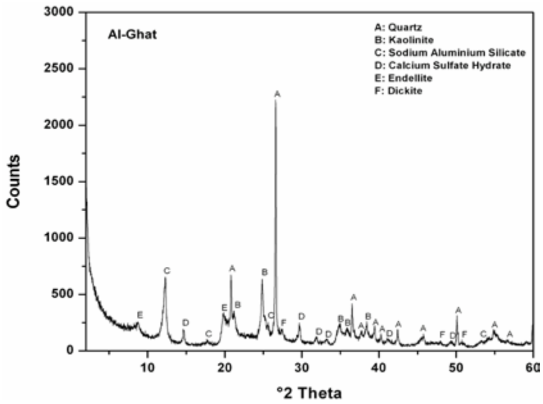

Fig.1. X Ray Diffraction analysis of Al-Ghat Soil

2.2 Lime

Analytical grade Calcium Hydroxide, supplied by Winlab Chemicals, UK has been used in the present study.

3. METHODOLOGY

3.1 Lime leachability test procedure

The target lime content percentages of 2 and 4 were mixed to Al-Ghat soil on dry weight basis. The maximum proctor density values corresponding to each percentage of lime addition shown in Fig. 2 were determined by employing mini compaction test procedure developed by Sridharan and Sivapullaiah [7]. From Fig. 2, as the lime content increases the maximum dry density values were found to reduce with corresponding increase in optimum moisture content for Al-Ghat. Remoulded samples with different lime dosages were tested for lime leachability in specially fabricated Perspex moulds, the details of which are shown in Fig. 3. The inside of the perspex mould was coated with a thin layer of silicon grease ensuring a good contact between the compacted material and the inner surface of the mould. All the tested samples were compacted to their maximum dry density and corresponding optimum moisture content values as per ASTM D5856-07 [8]. The top and bottom of the perspex mould were provided with perforated PTFE (Poly Tetra-Fluoro Ethylene) screens.

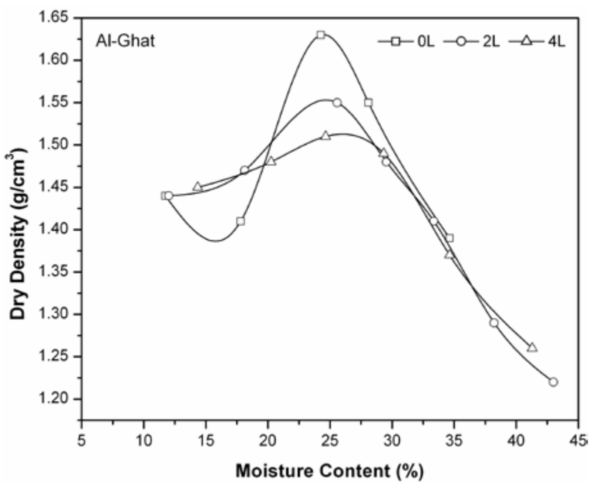

Fig. 2. Effect of lime content on the density characteristics of Al-Ghat soil

Chemically inert glass beads of 0.5 cm diameter were sandwiched between the two PTFE screens at both the ends enusring uniform flow of water. The perspex mould with the compacted specimen was kept in a desiccator maintained at a relative humidity greater than 95%, and cured for 7, 14 and 28 days. After curing the specimen, the perspex mould was fitted into the position and connected to ultra-chemical resistant tubing (Tygon). Millipore grade water (for neutral water conditions) and acidified water (using 0.1N HNO_3 for pH 4 condition) was allowed to flow through the specimen and the entrapped air if any was removed using the air vent provided at the top of the perspex mould and leachate was collected in the graduated cylindrical jars. The concentration of the calcium in the leachate was determined immediately by PinAAcle 900T Atomic Absorption Spectrometer.

4. RESULTS AND DISCUSSIONS

The leaching of calcium ions from pore solution forces the dissolution of calcium hydroxide which severely hampers the rate at which pozzolanic reactions proceed [2]. Hence in order to study the

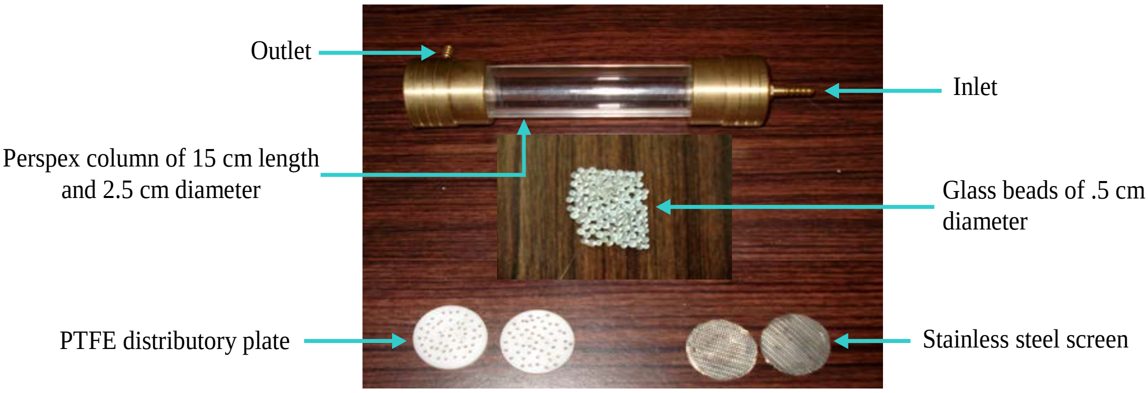

Fig. 3. Schematics of lime leachability test Apparatus

rate at which the calcium ions leach out from the lime treated clay matrix, water was allowed to flow through the compacted specimen continuously for seven days.

The effects of various parameters like lime, curing period and the pH of leaching solution on the lime leachability behavior have been studied in detail. Fig. 4 shows effect of flow and curing periods on the lime leachability behavior of Al-Ghat soil under neutral conditions at 2% lime content. Prima facie, it appears that the flow duration does not affect the lime leachability and these values remain consistently same from the third day onwards. With increase in curing period, the leachability values are drastically reduced as lime is converted from more soluble form to less soluble form of calcium silicate hydrates. The cementation products formed at higher curing periods harden the clay matrix thereby reducing the lime leachability values considerably. Similar observations were noticed by Moghal and Sivapullaiah [6], and Moghal and Elkady [2] under identical conditions for different tested soils.

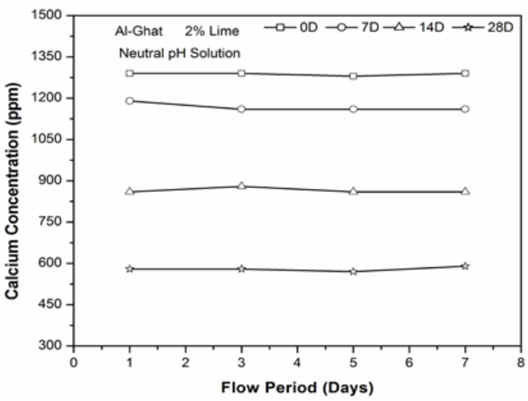

Fig. 4. Effect of flow period and curing period on the lime leachability behavior of Al-Ghat soil under neutral conditions at 2% lime content

With increase in lime content to 4%, the concentration of lime in the leaching fluid increases, particularly at lower curing periods as seen from Fig. 5. But with increase in curing periods, the solubility of silica from the clay is enhanced as the excess lime breaks the Si-O bonds in the silica rich phases of clay particles (Particularly Quartz as seen from Fig. 1). This dissolution of silica is better at 4% lime content compared to 2%, as it is nearer to the optimum lime content [9]. Apart from silica, alumina is also released from the mineral phase. This triggers a significant reduction in the lime leachability values at 4% compared to that at 2% lime addition at any given curing period.

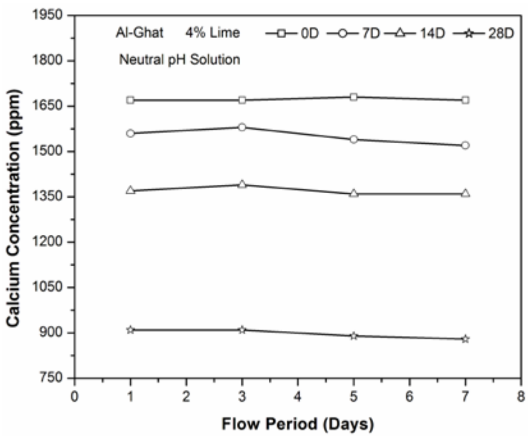

Fig. 5. Effect of flow period and curing period on the lime leachability behavior of Al-Ghat soil under neutral conditions at 4% lime content

4.1 Effect of Nature of Leaching Solution on the Lime Leachability Behavior

The surface of clay particles is rich with oxides of SiO_2, Fe_2O_3 and Al_2O_3 as seen from Fig.1. When the pH of the leaching solution is reduced it severely hampers the dissolution of lime from clay matrix from these oxide surfaces. From Fig. 6, at 2% lime content, when the pH of the leaching solution was reduced to 4, lime leachability values increased to 61% compared to neutral solution at a given curing period. However with increase in curing period, there is a significant reduction in the leaching of calcium ions from the stabilized matrix (Fig. 6).

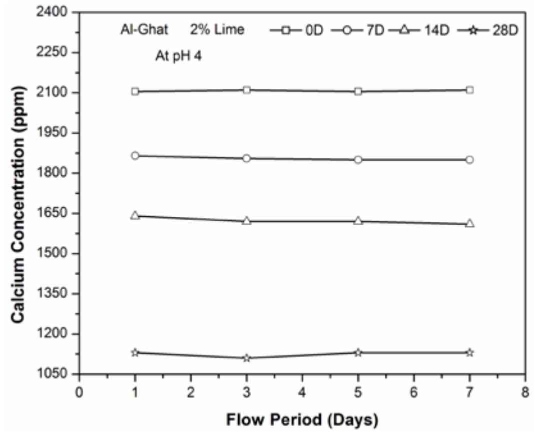

Fig. 6. Effect of flow period and curing period on the lime leachability behavior of Al-Ghat soil under acidic conditions (pH 4) at 2% lime content

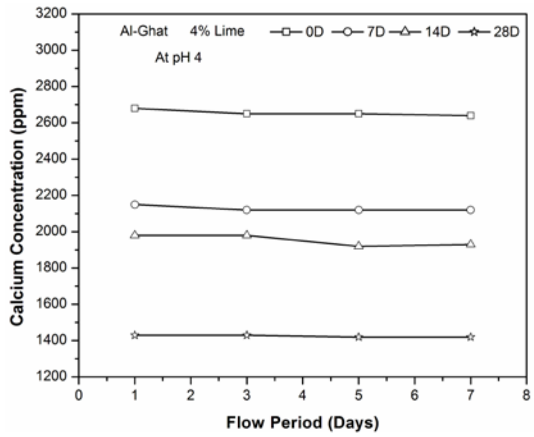

Fig. 7. Effect of flow period and curing period on the lime leachability behavior of Al-Ghat soil under acidic conditions (pH 4) at 4% lime content

Since soil lime reactions are time dependent, at lower curing periods, the cation exchange reactions (taking place between the ions such as sodium or potassium associated with the surfaces of the clay particles and calcium cations of the added lime) are predominant. This results in the modification of density of charged particles around diffused double layer. As a result when the pH of the leaching solution is reduced (around 4 in this case) the rate at which these cation exchange reactions occur are hampered, which result in increased release of calcium ions from the clay-lime matrix. This is particularly true at lower curing periods around 14 days as seen from Fig. 6. The duration of flow period does not affect the lime leachability values (Fig. 6).

With increase in lime content to 4%, even at lower curing periods, apart from cation exchange reactions, flocculation reactions become predominant, which in turn hold the calcium ions intact, thereby reducing the lime leachability values at any given curing period (Fig. 7). Further at this lime content (4%) in addition to primary soil-lime reactions, secondary reactions (cementation and carbonation) are pronounced as well, where in the dissolved calcium ions react with silicate tetrahedral and aluminate octahedral sheets from the clay mineral lattices at their edges forming calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) gels [10-12]. These cementitious gels are relatively in amorphous form at lower curing periods resulting at higher lime leachability values as seen from Fig. 7.

With increase in lime content from 2 to 4%, at a given curing period of 7 days, there is a 27% increase in lime leachability values, which is attributed to readily soluble gelatinous materials under aggressive environments (leaching solution pH 4). However with increase in curing period to 28 days, this difference in lime leachability values (at 2 and 4% respectively) reduces to 16.7%, as relatively more curing time is allowed which leads in the formation of cementitious compounds which are relatively crystalline in nature and are resistant to the acidity (pH 4) of leaching solution. Further, even at 4% lime content, the duration of flow period does not seem to affect the lime leachability values as seen from Fig. 7.

4.2 Practical Importance of the Study

Chemically modified clays have great potential in the construction of base liners for waste containment facilities. One of the most overriding requirements for efficient functioning of a landfill liner material is to possess lower hydraulic conductivity values as it controls the migration of leachate and its toxic constituents into underlying aquifers or nearby rivers. In most of the cases, the pH of the leachate varies drastically in the acidic range which dictates the prevailing hydraulic conductivity and issues related to durability. The current study tries to simulate the acidic conditions a landfill liner might experience when it is constructed with chemically modified (lime treated) clay.

The amount of lime retained invariably reflects the long term performance and consequently addresses the issues related to the durability of the selected clay as a material for liner in the construction of a landfill. In this study, the ability of Al-Ghat soil to retain the stabilizer (lime) under aggressive leaching conditions is investigated and it is observed that even at pH 4, at varying lime contents, the amount of calcium leaching from the clay matrix is reduced, particularly when the samples cured (as noticed from the curing period adopted in the study). Further, this study emphasizes and addresses the issues related to the use of locally available materials as a suitable choice for the construction of base liners for a landfills (both domestic and industrial).

5. CONCLUSIONS

The durability of lime stabilized clays depends on the amount of lime retained in the clay matrix particularly when they are prone to leaching. The calcium leaching from the lime stabilized clay matrix severely affects the performance of the material and in most cases, the selected material may not meet the desired requirements. In this study, lime leachability studies on Al-Ghat soil, stabilized with lime were conducted. The effects of various parameters like lime content, curing period and the pH of leaching solution on the lime leachability values were studied. It was observed that lime leachability values increased with increase in lime content at any curing period. At a given lime content, the lime leachability values reduced with the increase in curing period as relatively more time is allowed for the formation of cementitious compounds.

When the pH of the leaching solution was reduced (pH 4), relatively higher lime leachability values were obtained. With increase in curing period, these gelatinous amorphous cementitious compound transform to crystalline form which resist the leaching of calcium due to their poor solubility. It was obvious that the flow duration does not affect the lime leachability pattern.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] Lu N, and Likos W, “Unsaturated Soil Mechanics”, 2004, Wiley, New York.

[2] Moghal AAB, and Elkady TY, “Durability Studies on Expansive Soils Treated with Lime,” In the proc. of the International Conf. on Ground Improvement and Ground Control, 30th October to 2nd November 2012, held at Wollongong, Australia, 2012, pp.1187-1192.

[3] Chen FH, “Foundations on expansive soils”, 1988, 2nd Ed., Elsevier Scientific, Amsterdam, The Netherlands.

[4] Puppala AJ, Wattanasanticharoen E, and Hoyos LR, “Ranking of four chemical and mechanical stabilization methods to treat low volume road subgrades in Texas”, Transportation Research Record. 1819, Transportation Research Board, Washington, D.C., May. 2003, pp.63–71.

[5] Sivapullaiah PV, Subba Rao KS, and Gurumurthy JV, “Stabilisation of rice husk ash for use as cushion below foundations on expansive soils”, Ground Improvement, Vol. 8, No. 4, Jan. 2004, pp. 137-149.

[6] Baig MAA, and Sivapullaiah PV, “Role of Lime Leachability on the Geotechnical Behaviour of Fly Ashes”, International Journal of Geotechnical Engineering, Vol. 6, No. 1, Jan. 2012, pp. 43-51.

[7] Sridharan A, and Sivapullaiah PV, “Mini Compaction Test Apparatus for Fine grained Soils”, Geotechnical Testing Journal, Vol. 28, No. 3, May 2005, pp. 240-246.

[8] ASTM D5856 – 07, Standard Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall, Compaction-Mold Permeameter, 2007, West Conshohocken, Philadelphia.

[9] Sivapullaiah PV, Sridharan A, and Bhaskar Raju KV, “Role of amount and type of clay in the lime stabilization of soils”, Ground Improvement, Vol. 4, No. 1, Jan. 2000, pp. 37-45.

[10] Eades JL, and Grim RE, “Reaction of Hydrated Lime with Pure Clay Minerals in Soil Stabilization,” Highway Research Board, Washington, D.C. Bulletin No. 262, 1960, pp. 51-63.

[11] Bell FG, “Lime Stabilization of Clay Minerals and Soils,” Engineering Geology, Vol. 42, No. 4, July. 1996, pp. 223-237.

[12] Moghal AAB, Al-Obaid AK, and Refeai TO, “Effect of Accelerated Loading on the Compressibility Characteristics of Lime-Treated Semiarid Soils”, Journal of Materials in Civil Engineering, Vol. 26, No. 5, May 2014, pp. 1009-1016.

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