Improvement of Geo-engineering Properties of Expansive Clayey Soil by using Sodium Chloride and Bagasse Ash

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ABSTRACT— ***Expansive soils contain minerals such as smectite clays that are capable of absorbing water accompanied by shrink and swell behavior and thus change in volume. The swell–shrink behavior of these soils could lead to instability of the structures found on them, specifically the light-weight structures and pavements. Expansive clay soil is encountered in most parts of Egypt. A comprehensive study was made in Sixth of October city to investigate the impact of lime sludge and bagasse ash as an industrial solid waste from sugar-cane factory and sodium chloride salt on geotechnical engineering properties of expansive soil. The macrostructural properties are quantified through laboratory testing for Free swell index, Plasticity index and infiltration tests. The microstructural aspects of the treated soil are observed through X-ray diffraction studies and SEM micrographs. The laboratory results showed that by increasing the lime sludge, Bagasse ash and NaCl concentrations the liquid limit decreased from 100% to 60% while the plastic limit increased from 100% to 90% respectively. In addition, the infiltration tests showed an increase in the infiltration rate from 10% to 80% when LS and Bagasse ash were added to the soil also the free swell decreased from 100% to 70 % sufficiently. XRD patterns showed the formation of new kaolin cementitious compound as the change of montmorillonite to kaolinite mineral took place due to the reaction of high amount of calcium ions produced from the stabilizer, the cation exchange took place between the calcium cation of the lime associated with the surfaces of the clay particles. The effect of cation exchange and attraction causes clay particles to became close to each other, this process is called flocculation which is accompanied by a series of pozzolanic reactions resulting in the formation of clay aggregates that are bound together by the new cementitious products such as calcium aluminate. Scanning Electron Microscopic images (SEM) and SEM micrographs determined the formation of organized dense clay matrices of aggregations that showed the reduction of Montmorillonite clay mineral peak intensities and an increase in kaolinite clay mineral peak intensities due to the change of expansive soil texture and reduction of interplanar spacing of the treated soil.***

Keywords— Montmorillonite, Swelling Soil , Expansive Soil , Swelling Characters , NaCl Treatment

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1. INTRODUCTION

Expansive soil is a partially saturated soil of plastic clay that has the ability to expand when water is added and shrink when they dry out. Expansive soils experience volumetric change as a result of their water content variation [20] The expansive soil is widely spread in the Egypt especially in arid regions, where conditions are suitable for the formation of clayey minerals of the smectite group such as montmorillonite smectite, bentonite, beidellite, vermiculite, attapulgite, nontronite, and chlorite. These active clays are characterized by very small particle size, a large surface area and a high cation exchange capacity which can absorb water between its lattice structure. These characteristics cause an increase in the volume of the interlayer space, and an expansion of clay particles through an intracrystalline swelling. Such soils have low to moderate strength, moderate to high plasticity, and high volumetric change properties Holtz, [15,17]. The expansive soil is considered as problematic soil as the volume-change behavior of these soils pose a great threat to lightly loaded structures and specifically, pavements [6,3]. Replacing the existing soil might not be a feasible option therefore; the best available approach is to stabilize the soil with suitable stabilizers. This paper studies the effect of lime sludge on chemical and engineering properties of expansive soil in Egypt; as well as the addition of a small amount of chloride salt to swelling clay provides free cations which can accelerate the interlayer cation exchange reaction, it also promotes dissolution of clay minerals, which provides free silica and alumina that are essential for the development of pozzolanic cementitious products such as kaolinite [17] .Today's modern world faces the problem of management of variety of solid wastes which pose serious health and environmental problems. Among various waste materials, one of these such as lime sludge and Bagasse ash which generated from sugar industry, which poses serious environmental problems if not managed in a scientific way. Therefore, an attempt has been made to avoid the environmental problems caused by its large-scale dumping and to help in sustainable development of environment.

2. LITHOSTRATIGRAPHY OF THE STUDIED AREA

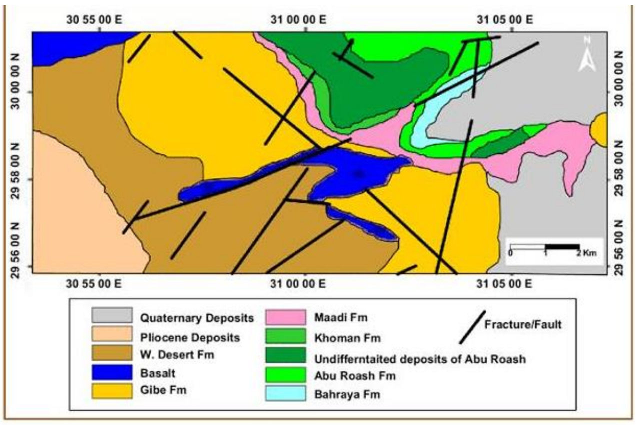

Fig.1 The rocks that are exposed in 6th October City can be subdivided into the following units, from bottom to top.

l-Eocene Limestone Thebes: Upper Eocene rocks follow the khoman chalk with an angular unconformity. Middle Eocene rocks follow immediately upon the chalk. The lower middies Eocene follows unconformably over the Chalk. The Eocene rocks are not different from the rocks described from the Giza Pyramids plateau [18].

2-Oligocene Basalt flow: On the top of the upper Eocene rocks a conspicuous basalt flow which is followed by gravel and sand deposits that make the enormous plain stretching around the entire structure. The sands and. gravels include abundant fossil wood. Hydrothermal effects of this Tertiary volcanicity can be seen in the silicification of some Eocene limestones and in the dolomitization of some beds of the limestone series [18].

3- Miocene: The larger part of the northern Western Desert as 6e of October City is covered by a thin blanket deposit of Miocene rocks that unconformably overlap older strata. In the east of lower Miocene, sediments rest over the weathered basalt flows or Oligocene sediments, thus marking a major period of non-deposition and erosion. The top of Miocene interval is marked by the unconformity union which the coastal gently-dipping Pliocene sandstone and shales rest [18].

Fig.2 Location map of the study area

3. MATERIALS

3.1 Soil

Expansive Soil sample was collected from Cairo, Egypt, The 6th of October area is bank of the Nile valley to both the north and south of Giza along 29° 57' 9.5544" N latitude and 30° 55' 18.9084" E longitude as shown in the map. The soil is light brown in color. Laboratory tests were carried out to determine the geotechnical properties of the soil sample such as consistency limits and free swell index, A summary of geotechnical properties of soil sample is given in Table 1. Soil properties. The 6th October soil had a very high degree of expansion and severe degree of severity while according to (ASSHTO) classification system based on Casagrande plasticity chart that the soil is classified as an extra highly plastic clayey soil. The chemical constituents of soil sample are given in Table 2.

Table 1 - Geotechnical properties of soil sample.

Property	Value
Liquid limit %	96.4
Plastic limit %	33.9
Plasticity index %	62.6
Free – Swell %	210
AASHTO classification	A-7-6
Color	Light brown

Table 2 - Chemical constituents of soil sample

Properties	Value
Hydrogen Ion Concentration (PH)	8.5
Electric Conductivity (EC) (mmhos/cm)	5560
Total dissolved Salts (TDS) %	3.560
Chloride Content (Cl) (ppm)	1780
Sodium Chloride (NaCl) (ppm)	2935
Organic Matter (O.M) %	1

3.2 Lime Sludge (LS) and Bagasse Ash

Samples were collected from Abou Korkas sugarcane mill that located in El Menia, Egypt. LS chemical properties were tested in laboratory, and corresponding results are summarized in results in (table 3).

3.3 Sodium Chloride Salt (NaCl)

salt is an ionic compound with the chemical formula NaCl representing a 1:1 ratio of sodium and chloride ions produced by Egyptian Salts and Minerals Company (AMISAL).

4. METHODOLOGY

Basic laboratory tests such as Atterberg's limit, free swell and infiltration were carried out on the expansive soil sample, the stabilization of soil with the lime sludge is carried out by blending the soil with different percentages of lime sludge (3%, 6%, 9% and 12%) and constant ratios of NaCl equal to (1, 2 and 3%) in order to determine the strength behavior of the soil with the admixture.

4.1Chemical Analysis

The chemical analysis is important to identify the chemical characteristics of the treated expansive soil. This chemical analysis comprises the soil reaction (pH), total dissolved solids (TDS), chlorides, oxides and loss on ignition. The results are tabulated in milligrams per liter (mg/L or ppm) and percentage (%). Laboratory test were conducted at the Construction Research Institute (CRI) of the National Water Research Center to determine the effect of ion cation exchanges associated with the microstructural behavior of the treated soil. [19].

4.2 Geotechnical Engineering Tests

4.2.1 Atterberg limit tests

In the laboratory, Casagrande's apparatus has been used to determine the Atterberg limits. In present geotechnical engineering practice, we usually use the liquid limit (LL), The plastic limit (PL), and the plasticity index (PI). Since the Atterberg limits are water contents where the soil behavior changes, these limits can be expressed in terms of water content continuum as shown in Figure 3. In this figure the types of soil behavior given with the ranges of water contents are associated with (stress – strain curves) corresponding to those states. Liquid limit is the percentage of water content at which the soil has such small shear strength that it flows to close a grove of standard width when jarred in an 18 specified manner, Plastic limit is the water content at which the soil begins to crumble when rolled in to thread of specified size while the plasticity index is simply the numerical difference between the liquid limit and the plastic limit and indicates the magnitude of the range of moisture content over which the soil remains plastic. PI = LL-PL It is the measure of the cohesion qualities of the binder resulting from the clay content [5].

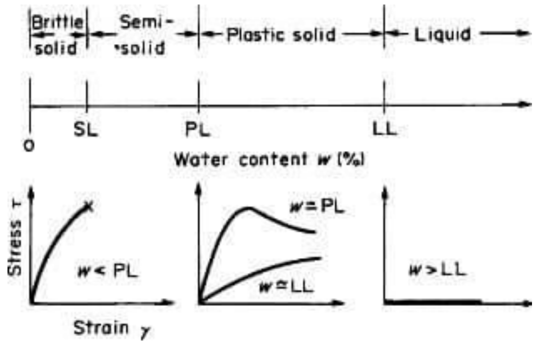

Fig.3

4.3 Free swelling test

This method was suggested by Holtz and Gibbs (1956) to measure the expansive potential of cohesive soils [15]. The free swell test gives a fair approximation of the degree of expansiveness of the soil sample, The procedure consists of pouring very slowly of 10 cubic centimeters of that part of the dry soil passing No. 40 sieve in to 100 cubic centimeters graduated measuring cylinder and letting the content stand for approximately 24 hours until all the soil completely settles on the bottom of the graduating cylinder. Then the final volume of the soil is noted.

$$\text{Free swell} = \frac{\textit{Final volume} - \textit{Initial volume}}{\textit{Initial volume}} * 10$$

4.4 Combined 1-D swelling and infiltration

A new laboratory test is proposed to measure the swelling and infiltration in clays with one simple test "the swelling infiltrometer", The results from the swelling infiltrometer tests confirm that the effect of the NaCl and Lime sludge as an additive to significantly increase the filtration and decrease the swelling potential of clays containing high percentages of montmorillonite mineral [9]. An infiltration test by using infiltrometer has been made on randomly chosen soil samples of 12% and 20% LS with 1%, 2% and 3% NaCl. An important property in studying swelling clay behavior and improvement is the speed at which water penetrates into the soil. This property is known as infiltration [9]. The rate of infiltration is usually measured by the depth, in mm, of the water layer that can enter the soil in one hour. An infiltration rate of 15 mm/h means that a water layer of 15 mm on the soil surface will take one hour to infiltrate. In dry soil, initially, water infiltrates rapidly and this is called the initial infiltration rate. As more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a steady rate, known as the basic infiltration rate. Thus, aggregate swelling for NaCl solution is possibly controlled by both crystalline swelling and double layer swelling between quasi-crystals.

4.5 XRD and Micro Scanning Microscopy

Scanning Electron Microscopic studies were carried out on treated and untreated soil for fabric study. Samples were allowed to dry at a controlled temperature of 30℃ to 40℃ for period of 2 weeks. The dried specimens were then broken by hand into small cubes of size 10mm X 10 mm X 10 mm and the fractured surface perpendicular to the direction of compaction was used to study the fabric orientation. Sample was spread on double sided conductive carbon tape fixed on the stub and placed in the sample chamber of SEM. After attaining high vacuum, the filament was switched on the virous parameters like electron beam, intensity spot size voltage and emission current were adjusted and the images were capture. Xray Diffraction test were performed on untreated soil specimens to determine the mineralogical changes dealing with microstructural alterations. Samples were dried, pulverized with mortar and pestle and sieved through 0.075mm sieve. Fine powdered less than 1gm was placed in the specimen holder, for diffractometer analysis. This holder was then mounted on analytical X-Ray powder diffractometer with a ceramic Cu-X-ray tube for XRD analysis [7] . The range of 2Ɵ was from 2º to 6ºwith 0.067º step size. Diffractograms obtained by the analysis of JCPDS software to determine the various minerals present in the soil sample.

5. RESULTS AND DISCUSSION

5.1 Chemical Analysis results

5.1.1 The effects of cation exchange on the geotechnical properties of the soil

In order to understand the physical properties of the clay minerals. The clay minerals have two basic building units made of silica tetrahedral sheets and alumina octahedral sheets which can extend indefinitely in two directions, these basic building blocks are bonded together to build up the clay minerals. Montmorillonites (Si8Al4O20(OH)4 ·nH2O) Film-like shape consists basically of two tetrahedral silica sheets with an octahedral alumina sheet sandwiched between them. Montmorillonite always has ionic substitutions of Fe++, Fe+++ and/or Mg++ for Al+++ in the octahedral sheet while in some cases Al+++ for Si++++ in the tetrahedral sheets. Substitutions between cations may occur in the tetrahedral and octahedral sheets, resulting in different charge deficits. These negative charges attract cations which are inserted between the layers in the interlayer space. [14] Crystallization of montmorillonite is not stable since the layers are bonded by weak Van der Waals forces what makes the interlayer space very variable. This allows easily expansion of the crystals and the entry of water molecules and cations as the water molecules wedge into the interlayer so the cations become fully saturated which results in repulsive forces and swelling in clay layers as shown in figure 4 . In this study an admixture of different lime sludge (Bagasse ash) ratios (3, 6, 9 and 12 % by weight of 6th of October soil) and constant ratios of NaCl equal to (1, 2 and 3%) are added to improve the swelling behavior of expansive soil. By adding this admixture, a series of pozzolanic reactions take place between the interlayers of the smectite minerals resulting in an increase in pH Levels due to the formation of Calcium silicate hydrate and sodium silicate hydrate [4]. This pozzolanic reactions consume part of the soil's water content. This is preferable in terms of engineering performance of the stabilized soil, as the soil become stiffer and produce stronger, cementitious soil matrices.

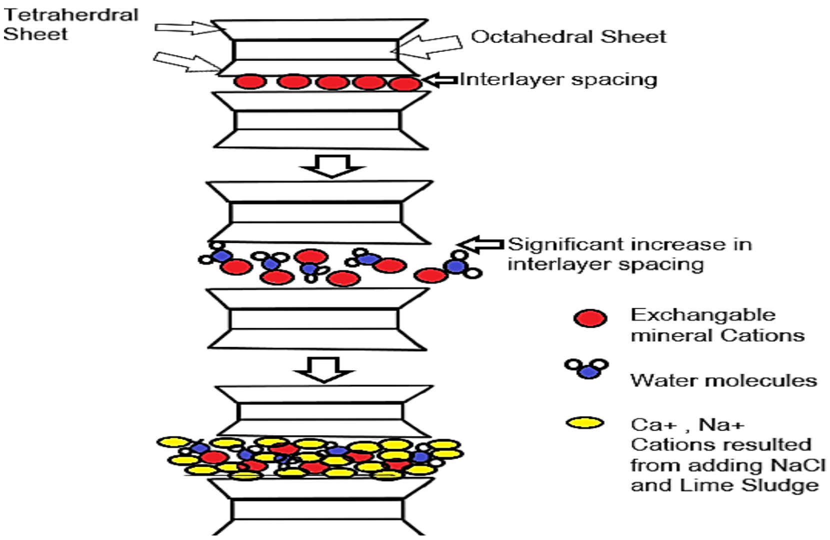

Fig.4: New cementitious compounds are formed between the soil's interlayers when adding Lime Sludge and NaCl constituents

5.2 The effect of LS and NaCl treatment on Geotechnical properties of the soil

5.2.1 The Atterberg consistency limits

The results have shown that by adding an admixture of Lime Sludge 3%,6%.9%and 12% with 1%,2% and 3% NaCl respectively, the liquid limit and plastic limit values decrease significantly by increasing the amounts of NaCl and LS [2] as shown in fig.7.

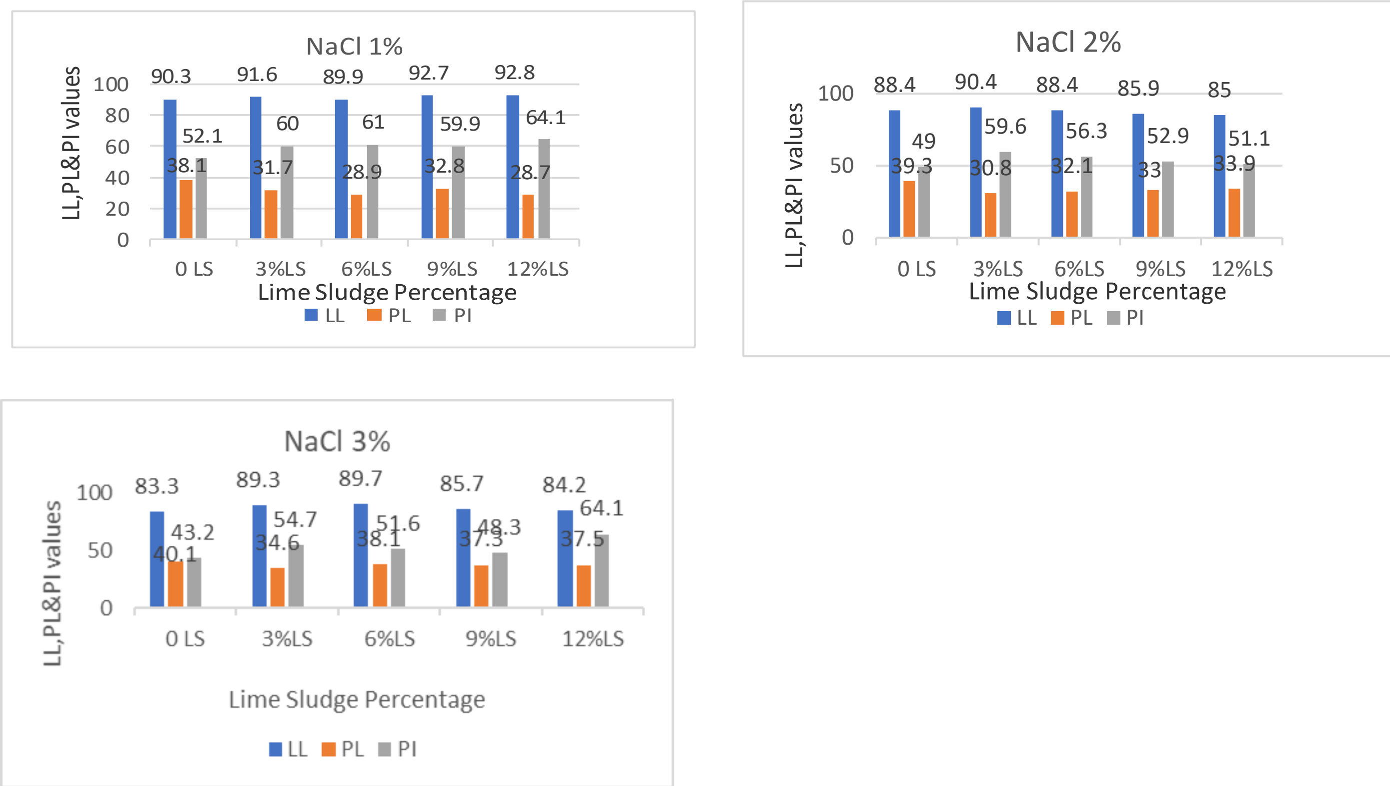

Fig. 5. Plasticity Index decreases and liquid limit decrease while Plastic limit increases when adding Lime Sludge 3%,6%,9% and 12% respectively in 1%, 2% and 3% NaCl.

5.2.2 Free Swell

The free swelling values are affected by adding NaCl and LS to the stabilized samples using LS amounts of 3%,6%,9% and 12% respectively. There is a slight gradual reduction in free swelling values from 100% to 50 % achieved by NaCl 1% while a great reduction appears from 100% to 40% when adding 2% NaCl to the stabilized samples. A final great further reduction took place when adding 3% NaCl about 70 % from the initial value, whereas by increasing the LS and NaCl constituents the free swelling values decrease significantly as shown in fig 8.

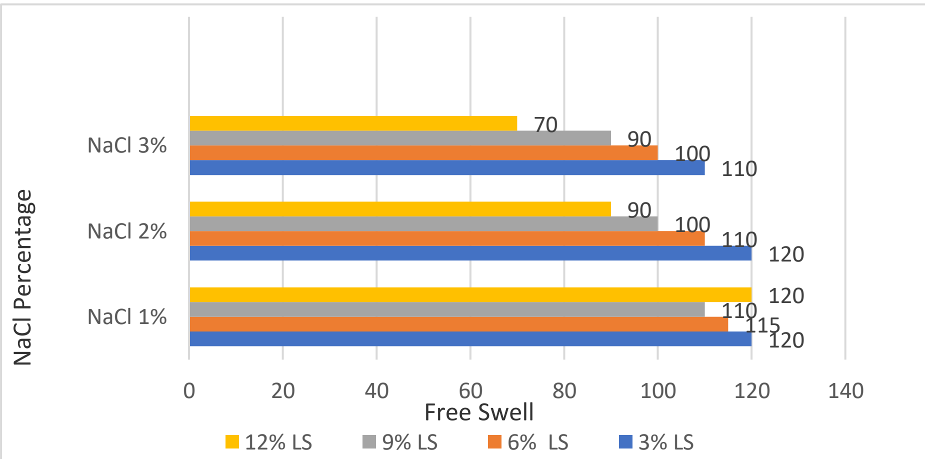

Fig. 6: Variation of free swelling of the soil sample after NaCl and LS Treatment.

5.2.3 Infiltration test results

The laboratory results showed that by increasing the percentages of LS from 12% to 20% and by adding 1%,2% and 3% of NaCl solution the infiltration rate increases till it reaches its maximum increase 30% from the initial value of infiltration while the swelling ratio decreases alternatively as shown in Fig.9 and Fig.10.

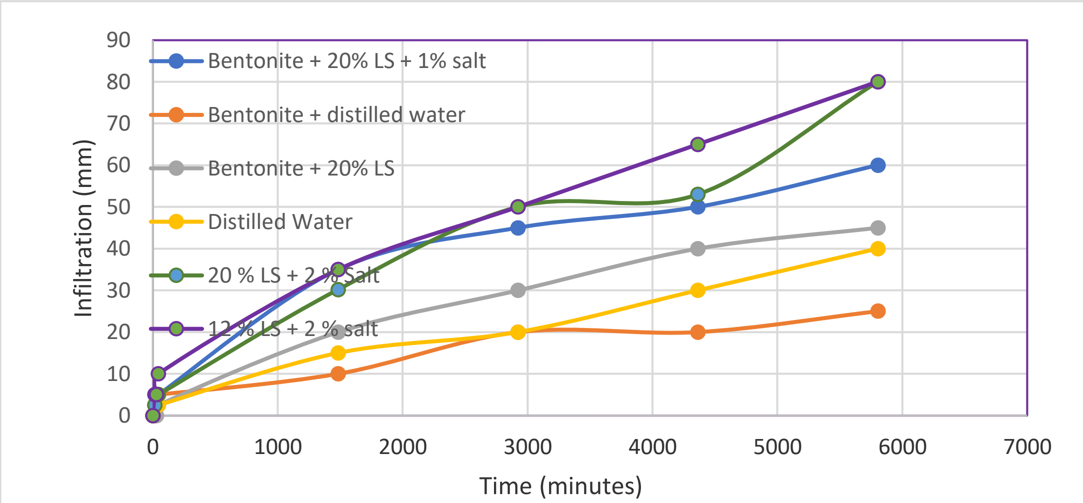

Fig.7: Variation of infiltration rate values after adding 12% and 20% LS & 1% and 2% NaCl.

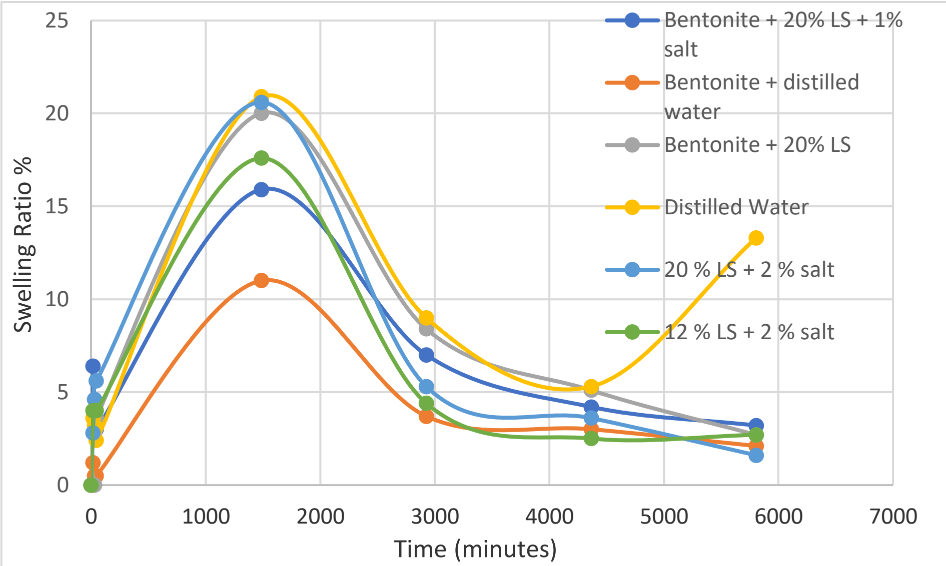

Fig .8.: Variation of Swelling ratio% after adding 12% and 20% LS & 1% and 2% NaCl.

5.3 XRD and SEM Analysis

5.3.1 Mineralogical studies using XRD

XRD patterns of the treated and untreated soil specimens are observed in Fig. 13. The XRD pattern of the untreated soil shows characteristic peak of montmorillonite 50% peaks (2θ = 6.7°and 19.8°), Calcite 29% peaks (2θ=*26.6° and 47.5°)* and quartz 77% peaks (2θ =20.8°,39.4°,42.4°,47.5°,59.9°and 68.2°) and kaolinite 16.6% peaks (2θ = 12.3°and 34.8°) Fig.18-a.The addition of lime and NaCl changes the original minerology of the soil through suppression, broadening and smoothening of the existing peaks as shown in fig.13.b due to the decrease in the crystallite size that causes an increase in the width of the diffraction results in wide broadened peaks that indicate the interaction between the additive and the soil, Alternatively, XRD pattern of lime-treated soil shows several small peaks and the intensity of the existing mineral peaks are reduced as the d-spacing between atomic planes decreases. There is a considerable suppression of the Montmorillonite 14.59 % peaks (2θ = 6.9°,29.4°,19.8° and 31.6°) ,degradation of the quartz 50% peak at (2θ = 26.6° and 50.2°) and significant increase in Kaolinite 25% peaks (2θ = 12.2°,31.6° and 40.3°) as shown in Fig.13.b also the disappearance of some peaks such as calcite peak took place , This could be attributed to the initial cation exchange reactions and the formation of semi crystalline or amorphous cementitious compounds such as C-S-H and C_3AH_6 which offers sufficient strength to lime-treated soil . The disappearance of calcite peaks indicates alteration in the structure of the clay though it is not destroyed completely. The mineralogy changes indicate an equivalent behavior to the response of treated soil for index and engineering properties. [13]

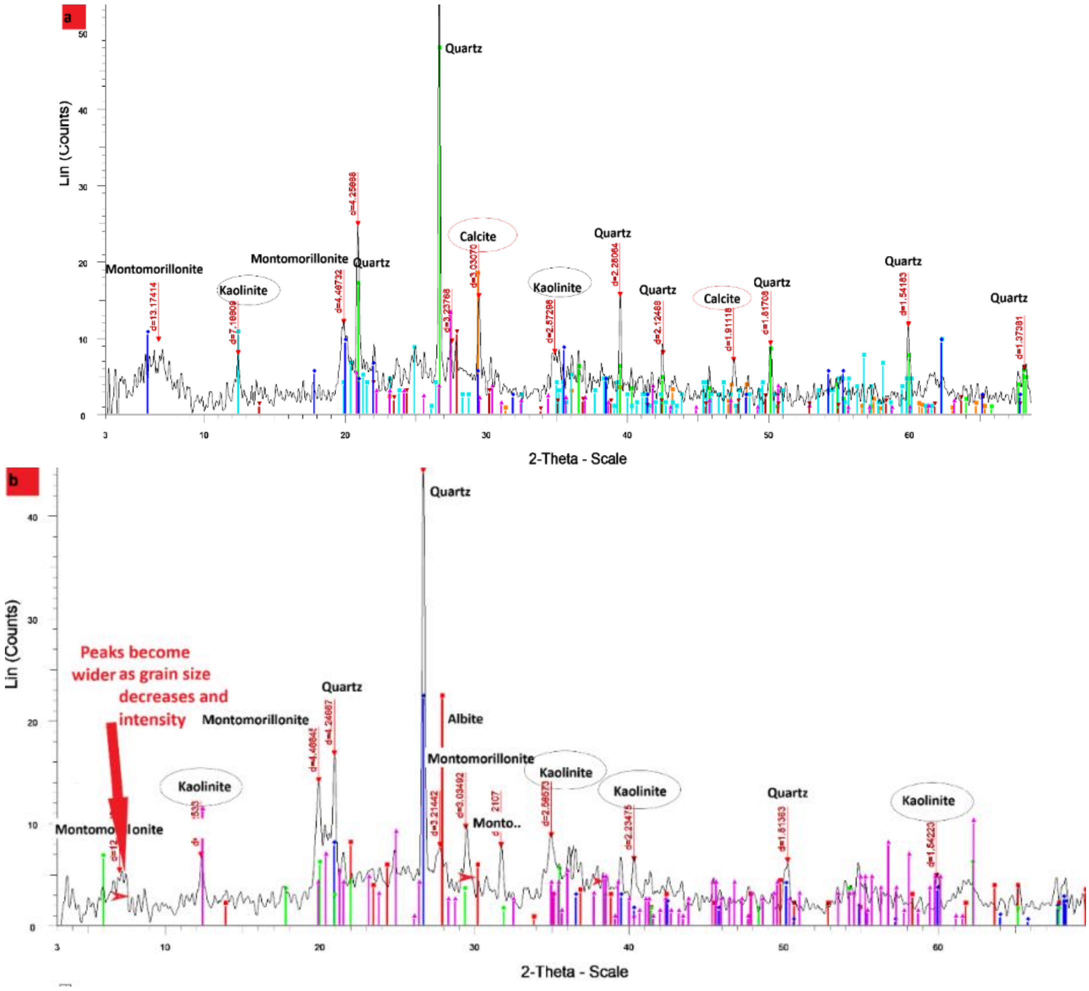

Fig.9 XRD analysis for (a) untreated soil and (b) treated soil.

5.3.2 Microfabric studies using SEM

The SEM images of natural untreated soil were observed with a smooth dispersed fabric, wavy with visibly larger void spaces with high plasticity as shown in Fig.11 while on stabilization, certain amount of lime is added to the clayey soil minerals such as montmorillonite, kaolinite and smectite. The fabric of clay soils was changed due to sharp-edged, split like structure with denser surface as shown in Fig 11-b. The clay particles tend to clump together to form larger particles. Hence, expected to decrease the liquid limit, increasing the plastic limit, reducing the plasticity index and improving the strength and deformation properties of soil [16]. The pozzolanic reaction may continue for a long time, so the pozzolanic reaction is expected to generate the hydration process between LS and soil particles as shown in Fig11-c. As a result of the reaction between clay minerals and lime, calcium silicate gel (C-S-H) is formed as shown in Fig 11-b. The gel fills the pores and acts as a binder between the soil particles, thereby increasing the soil strength. The formation of cementing products such as Kaolinite minerals induced a decrease in pore spaces as the strength development is related to the microstructure due to fabric and cementation. XRD and SEM analysis were carried out on compacted soil samples before and after LS and NaCl treatment as shown in fig.11-a and 11-b. From the SEM images of lime mixtures obtained with different percentages, the microstructures of the clay sample contain fewer flaky layers with an increase in the lime percentage due to formation of Calcium mixed with C-S-H gel, the microstructures of the clay sample contain a clear precipitation of calcium carbonate on the surface (fig 10-d). When the percentage of lime and NaCl increase more flocculated structure and aggregated structure are significantly formed shown in fig 10-d, this causes the pores between the pellets to decrease due to flocculation. Finally, the formation of Tricalcium aluminate C_3AH_6 were observed after the treatment as shown fig 11-f. The results show that by increasing the amount of lime and NaCl leads to an increase in the pozzolanic reactions which form new kaolin cementitious compounds (fig 11-f) that produce strong bonds among clay particles.

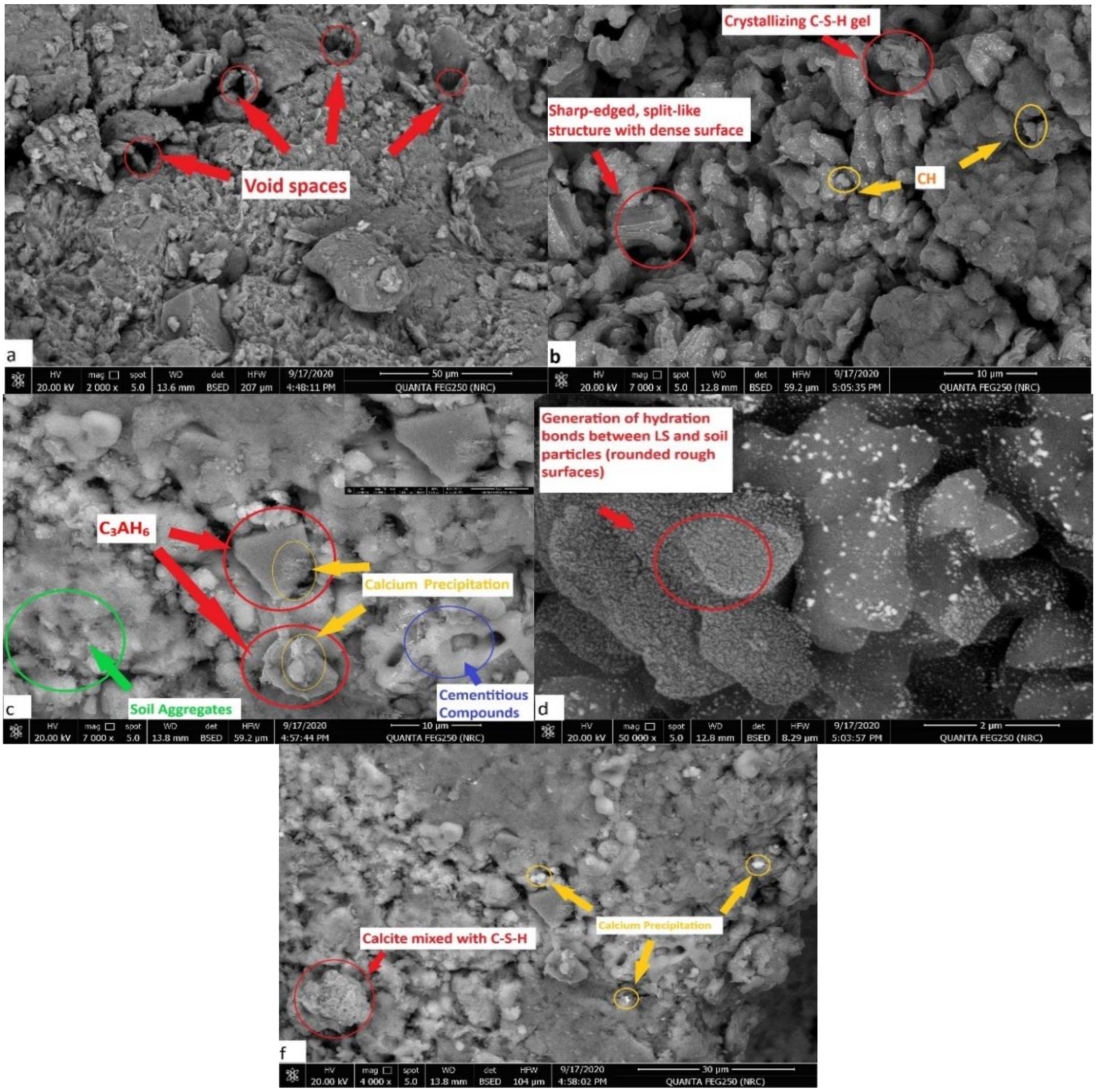

Fig.10: a) untreated natural soil, b) treated soil by adding LS &NaCl, c) The presence of soil aggregates of treated soil due to the formation of C-A-H, d) The reaction between LS and soil particles and f) The formation of calcite mineral mixed with C-S-H

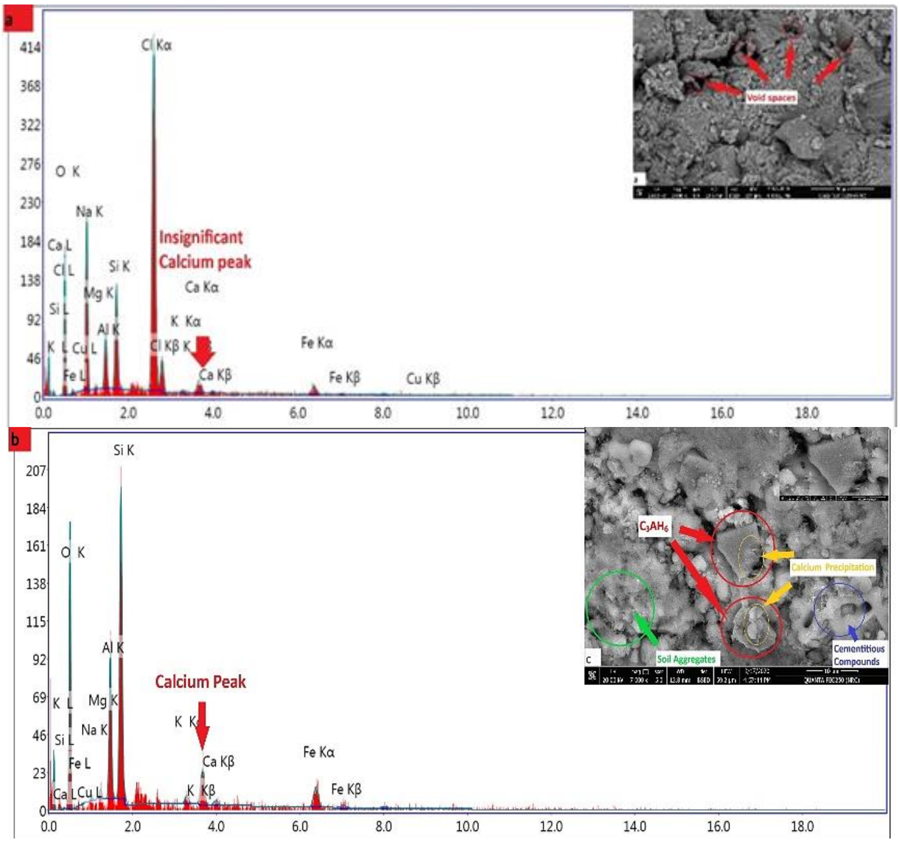

Fig 11: a) untreated expansive soil and b) treated expansive soil

From SEM and EDX analysis it has been observed that the untreated expansive soil has limited amount of Calcium as no significiant amount of Ca peak (0.83 atomic weight %) shown in Fig. 11-a while in Fig. 11-b after the treatment a significant amount of calcite precipitation is obtained from the Ca peak increased (5.5 atomic weight %) which acts as a binder between soil particles.

6. CONCLUSION

According to the high percentage of clay minerals montmorillonite, smectite and chlorite in the expansive soil the swelling potential is very high. The untreated soil is composed of voided clay matrices with dispersed structure which causes the soil to swell when hydrated. The effect of LS activated by a suitable amount of NaCl has a great effect in decreasing the swelling nature of the expansive soil. Atterberg limits as the geotechnical tests showed an a decrease in liquid limit 60% from the initial value, In the infiltration test it has been confirmed that the effect of the LS &NaCl tends to significantly increase the filtration from 10% to 80% and a further decrease was achieved in the free swell values till 70% from the initial value while The X-ray diffraction showed that the d-spacing between mineral atomic planes is reduced resulting in wider and broaden peaks correlated with small peak intensities as the montmorillonite was approximately transformed to a non-swelling clay mineral kaolinite due to the reaction between the additives and the treated soil. Microscopic images (SEM) and SEM micrographs determined the formation of organized dense clay matrices of aggregations that showed the reduction of montmorillonite clay mineral peak intensities from 50% to 14.59 % and an increase in kaolinite mineral peak intensities from 16.6 to 25% due to the change of expansive soil texture and reduction of interplanar spacing of the treated soil.

7. ACKNOWLEDGEMENT

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