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CLAYEY SOIL TREATED BY CEMENT AND QUICKLIME BY MICROSTRUCTURE: A MINERALOGICAL ANALYSIS

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Soft clayey soil was treated by a combination of cement (PC) and Quicklime (LQ) in order to modify and stability. This study shows an improvement of clay soil brought from Garma Ali site in the Al Basra governorate, Iraq. The PC was added in percentages of 0, 2, 4, 6, 8, and 10%, and LQ was added to 2 and 4%, of dry weight. Also, this research used Microstructure Analysis by Scanning Electron Microscope (SEM) testing and Mineralogical Analysis by X – Ray Diffraction (XRD) testing on the examination soil treated with mix between cement (PC) and Quicklime (LQ) for the purpose of knowing the reasons for the increase in the shear strength and decrease maximum dry density. Through the micrographs that result from the scanning electron microscoping and the curves of X-ray that demonstrate presentence, the formation of the hydration reaction product (CSH gel) shows tiny bristle (rod) crystals. The CSH gel and the tiny bristle (rod) crystals worked on coating and contact the particles together. The micrographs for soils treated with (2% LQ + 10% PC) show an increase in the amount hydrated gel (CSH) compared to the soil treated with 6% PC and 2% LQ and 8% PC and 4% LQ, but the number of bristle–like crystals decreases compared to soil treated by 8% PC and 4% LQ.

Keywords: Scanning electron microscoping (SEM), X – Ray Diffraction (XRD), UUU test, CSH (calcium silicate hydrate), Dolomite (D).

1 INTRODUCTION

Random data collected from several site investigation reports demonstrated the value of undrained shear strength at less than 30 kPa in Basrah governorate and less than 40 kPa in Maysan and Dhi Qar governorates; compression indices as high as 0.3 were also reported (Rahil 2007). Lime is used primarily to dewater the soil in order to improve the workability and its bearing capacity. This Lime modification is widely used for building embankment and subgrade of clayey soil since the effect is rapid and modifies the geotechnical characteristics of the soil like the plastic limit, the shear strength and the soil compaction characteristics. Later the pozzolanic reaction between the soil minerals and lime in the presence of water leads to the formation of secondary cementitious products (C-S-H, C-A-S-H) increasing the soil cohesion and its resistance (Boardman *et al.* 2001, Muller 2005, Maubec 2010, Nichloson 2014). Cement stabilization is quick, does not need mellowing time and provides a non-leaching platform (Sariosseiri and Muhunthan 2009). Furthermore, in practice, a mixed treatment with lime and cement is used since the mixture allows one to facilitate the workability without disturbing the effect of the cement and the gain of resistance in the long term. The addition of lime and cement exerts impacts on the material microstructure, and consequently, influences pore distribution over a very short term. Yet to this day, none of these efforts have provided a complete description of the full set of physicochemical mechanisms and their impacts on both the microstructure and macroscopic behavior. With this backdrop, the objective of the present study is to describe the effects of adding lime and cement on the characteristics of the treated softy soil by employing a multi-scale approach. To explain performance trends, the effects of adding lime and cement on the soil's physical chemistry and microstructure will be characterized.

2 EXPERIMENTAL OF INVESTIGATION

2.1 Materials Used

2.1.1 *Soils*

In this study, soil samples used were obtained from the Garma Ali site about 538 km south of Baghdad in Al Basra city. The engineering properties of clayey soils are presented in Table 1, which shows the grain size distribution of soils used.

Table 1. Physical and chemical properties of natural soils used.

Index Property	**Test Standard**	**Index Valve Garma Ali Soil**
Liquid Limit (L.L) (%)	ASTM D 4318	58
Plastic Limit (P.L) (%)	ASTM D 4318	27
Plasticity Index (P.I) (%)	ASTM D 4318	31
Specific Gravity (G.s)	ASTM D 854	2.75
Gravel (larger than 4.75mm) (G) %	ASTM D 422	0
Sand (0.075 to 4.75 mm) (S) %	ASTM D 422	2
Silt (0.005 to 0.075 mm) (M) %	ASTM D 422	35
Clay (less than 0.005mm) (C) %	ASTM D 422	63
Classification (USCS)	ASTM D 2487	CH
Calcium Oxide (CaO) (%)	Chemical Analysis	21.12
SO3 Content (%)	Chemical Analysis	0.38
Total Dissolved Salt (TDS %)	Chemical Analysis	1.73
Total Solved Salt (TSS %)	Chemical Analysis	6.89
PH Value (%)	ASTM D 4972	8.69
MDD (KN/m3)	ASTM D 698	16.5
OMC (%)	ASTM D 698	20.5

2.1.2 *Types and properties of additives*

The cement used to be sulfate resistance Portland cement (type V) manufactured by (Al Jessir) factory made in Iraq. The type of lime used was quicklime (unhydrated) manufactured from limestone by the Alnoora factory in Kerbella governorate.

2.2 Laboratory Tests

A series of laboratory tests consisting of, compaction, UUU test, scanning electron microscope (SEM) and mineralogical analysis by x – ray diffraction (XRD) were conducted on clayey soils. The combinations of Portland cement and quicklime (PC and LQ) were used for stabilization of the two soils. The percentages of PC were 0, 2, 4, 6, 8 and 10%, while the percentages of LQ were 0, 2 and 4%.

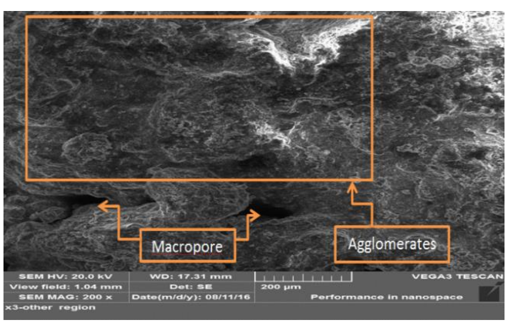
3 RESULT AND DISCUSSION

3.1 Microstructure Analysis by SEM and Mineralogical Analysis by XRD

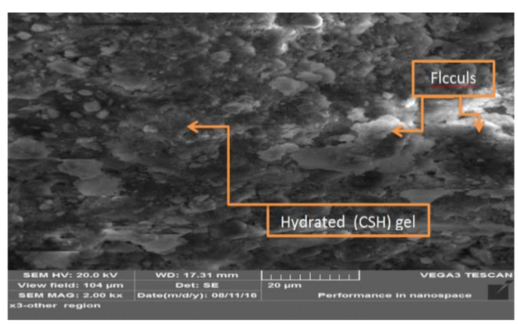
The microstructure refers to fabric that is the arrangement of the particles, particle group and pore spaces in the soil as well as cementation. The changes of microstructural development in the two tested soils due to PC and LQ addition play a significant role in the geotechnical properties and the mechanical behavior in these stabilized soils. It was noted in this study that the cohesion strength (C) in soils treated with proportions 8% PC and 4% LQ is higher than that of soils treated with 10% PC and 2% LQ. Therefore, Microstructure Analysis by Scanning Electron Microscope (SEM) and Mineralogical Analysis by X – Ray Diffraction (XRD) tests were performed for the purpose of knowing the cause of this convergence, Also, soils treated by 6% PC and 2% LQ in order to be compared with higher ratios from soils treated were examined. The scanned image was obtained in the magnification range from 50 to 20,000 times.

3.1.1 *Treated stabilized soil with 6% PC and 2% LQ*

Figure 1 illustrates a micrograph of treated soil. The micrographs of the treated soil with 6% PC and 2% LQ show crumbs of floccules with a porous nature and cementitious compounds (calcium silicate hydrate) coating the clay particles. Additionally, the reaction of the composite (PC and LQ) with clay led to the formation of aggerates of various sizes. It can be seen in both treated soils that there is a micro fabric silt – fine sand like structure. Figure 2 shows XRD pattern for untreated soil and Figure 3 illustrates XRD pattern for treating soil and with 6% of PC and 2% of LQ, respectively. For treating soil with 6% PC and 2% LQ, calcite ($CaCO_3$) shows a small increase in quartz (SiO_2) content, while feldspar and dolomite ($Ca(MgCO_3)_2$) show a slight reduction in its content. CSH has intense peaks centered on 26° and 28° for treated soil. SEM micrograph was the best technique to trace and confirm the CSH existence inside soil.



(A)



(B)

Figure 1. SEM micrograph of treated soil with 6% PC and 2% LQ (A) at a magnification 200 times. (B) At a magnification of 2,000 times.

3.1.2 *Treated stabilized soil with 8% PC and 4% LQ*

Figures 4a and 4b illustrate micrographs of treated soil stabilized with 8% PC and 4% LQ. The micrograph shows aggregated arrangement due to flocculation and the formation of the hydration reaction (CSH) product (CSH gel) coating and cementing the soil particles together. In addition to treated soil, the micrograph illustrates the formation of more new bristle-like crystals. The result from XRD reveals that crystals are mainly composed of Si and Ca. The SEM images of specimens illustrate that the stabilized clay particles are coated with massive, fibrous, calcium silicate hydrated (CSH) gel. The magnified figure for treated soil shows highly fabric compared to treated soil with 6% PC and 2% LQ and 10% PC and 2% LQ. These bristles fill the voids inside treated soil. The XRD of treated soil with 8% PC and 4% LQ is shown in Figure 5. Figure 4 shows a huge increase in quartz (SiO_2), in addition to the increase in calcite ($CaCO_3$), where this increase is much higher than treated soil with 6% PC and 2% LQ. So, the CSH present intense peaks centered on 27° for treated soil. The increase in silt– sized particle content leads to increase in the cohesion strength value of the stabilized soil is observed. Quartz (SiO_2) and Calcite contains hard minerals so the increasing in their contents made the cohesion strength to gain up. A reduction can be noticed in the content of montmorillonite, Feldspar, illite and kaolinite.

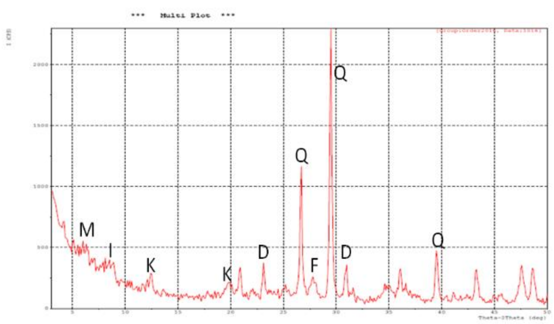


Figure 2. XRD of Natural Soil.

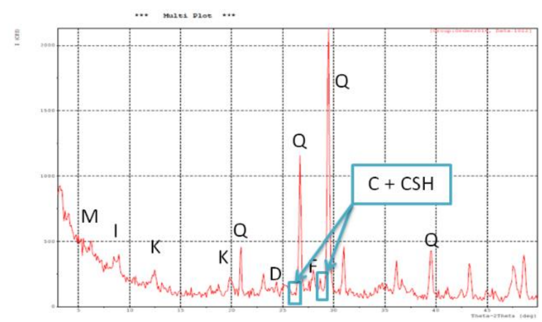
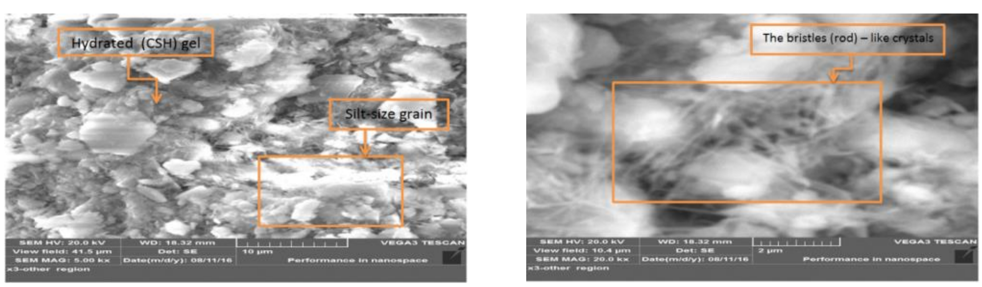


Figure 3. XRD analysis of treated soil with 6% PC and 2% LQ.



(A) **(B)**

Figure 4. SEM micrograph of treated soil with 8% PC and 4% LQ (A) at a magnification 5,000 times. (B) at a magnification of 20,000 times.

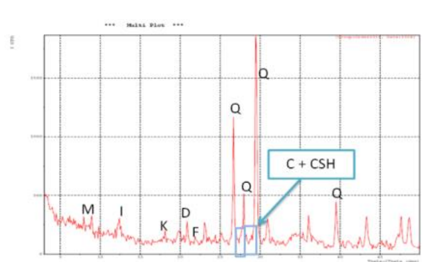
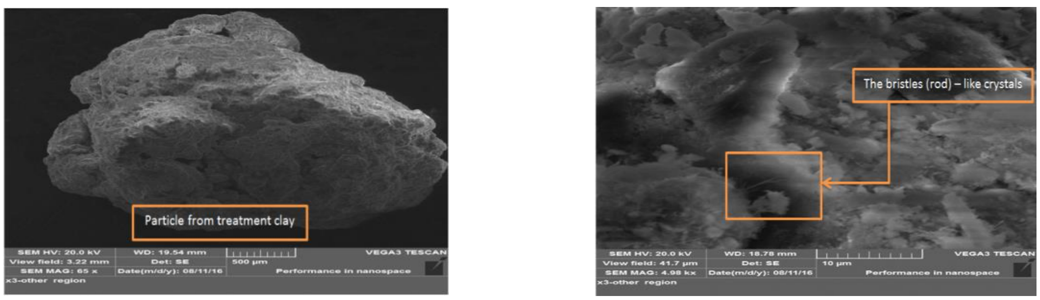


Figure 5. XRD analysis of treated soil with 8% PC and 4% LQ.

3.1.3 *Treated stabilized soil with 10% PC and 2% LQ*

Figure 6 illustrates treating sample of soil with 10% PC and 2% LQ, and Figure 7 shows an increase in the amount of hydrated gel (CSH) compared to soil treated with 6% PC and 2% LQ and 8% PC and 4% LQ, but the number of bristle-like crystals is decreased compared to soil treated by 8% PC and 4% LQ in the last two figures (as a result of pozzolanic reaction); it developed more aggregates. This implies that the sample has a high amount of hydration cement and pozzolanic products, and bonding among the clay particles, where it is noticed in the SEM image of treated soil, which represents a gathering of hydration cement and pozzolanic reaction products. XRD pattern of the treated soil with 10% PC and 2% LQ, shows a huge increasing in quartz content compared to the natural soil, while Figure 7 illustrates XRD for treated soil with 10% PC and 2% LQ increase in calcite, and an increase in quartz compared to treated soil where the increase is in calcite and then quartz. Calcium silicate hydrated (CSH) appears in both images of SEM and XRD of treated soil with 10% PC and 2% LQ as follows.



(A) (B)

Figure 6. SEM micrograph of treated soil with 10% PC and 2% LQ (A) at a magnification 50 times. (B) at a magnification of 5,000 times.

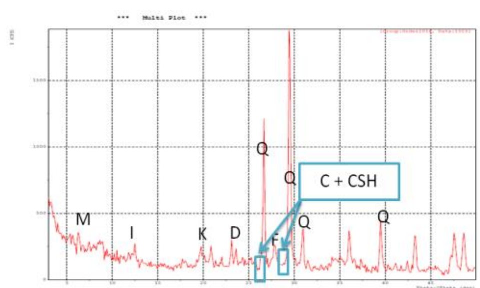


Figure 7. XRD analysis of treated soil with 10% PC and 2% LQ.

4 CONCLUSIONS

This study has demonstrated the effect of PC and LQ on compaction, UUU test and interpretation of some results by microstructure and mineralogical analysis of soft clay

A- The SEM-micrographs of treated soil with different PC and LQ content show crumbs of floccules with a porous nature and cementitious compounds coating clay particles. It can be seen that this soil has a microfabric silt-fine sand like structure.

B- Mineralogical analysis by X – ray diffraction (XRD) shows an increase in quartz and calcite. The increase in silt-sized particle content leads to an increase in the pore voids size. Hence, an increase in the cohesion strength (C) value of the stabilized soils is observed. Quartz and calcite contain hard minerals, so the increase in their contents made the cohesion of treated soil increase as well. A reduction can noticed in the content of montmorillonite, illite, and kaolinite clays compared to natural soil.

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