IMPROVEMENT OF SWELLING SOIL USING CEMENT DUST

[2]

Awad, S. A.(1); Elmashed, M. M.(2) and Zaher, S. S.(2)
1) Geology Department, Faculty of Science, Ain Shams University
2) National Water Research center, Construction Research Institute, El Khanater El Khiriya

ABSTRACT

The present work aims to study the utilizing of some industrial solid waste materials to improve the behavior of the problematic soils such as swelling soil and soft clay. The soil under study is taken from two regions; Sahl-Al Tinah in north Sinai and Toshka in southeastern of western desert. We have tried to use constant ratio of CKD equal to 20% mixed with small ratios of cement (6%, 9%, and 12%) with different percentages of soft clay and swelling soil. In this regard important techniques (XRD, SEM) were carried out to identify the mineralogy and microstructure changes before and after treatment. Geotechnical tests (e.g. Atterberg's limits, Compaction, Unconfined compressive strength (qu) and free swelling) were measured. The results showed that the dry density increases as the swelling soil ratios decrease and the soft clay ratios increase from (1.65 to1.74 gm/cm^3), the optimum moisture content (2o.19%). Unconfined compressive strength were increases as the swelling soil decrease and the soft clay increase from (30 to156.3) kN/m^2 at 90 days curing time and 6% cement, and it increases from (89.9 to 257.6) kN/m^2 at 90 days curing time and 9% cement, and increase from (215.9 to 389.8) kN/m^2 at 90 days curing time and 12% cement. The values of plasticity properties slightly decrease with gradually increase of soft clay percent and gradually decrease of swelling clay percent in all mixtures, free swelling decreased from (50% to 20%). XRD and SEM analyses after treatment showed that all clay minerals are transformed to new cementitous compounds, such as (C-A-H, C-S-H, and C-A-S-H), which has a more complex crystalline structure, as curing time increase.

Kaywords: Cement kiln dust, Soil stabilization, Cement, Problematic soils.

1. INTRODUCTION

Day by day technology increases and also the technology problems increase due to the accumulation of the waste materials. The disposal of this waste causing several adverse impacts on environment and pollute the soil, air and water. Many researches explain how to use the waste materials (CKD) in civil engineering as soil improvement. In this research we will try to use solid waste material (CKD) with very small amount of cement to make a soil stabilization for the natural problematic soil .The composition of the cement kiln dust is similar to raw materials of cement but the amount of alkalis, chlorides and sulfates is usually considerably higher in the cement kiln dust (Al-Refeai, 2000). Expansive soil deposits occur in the arid and semi-arid regions of the world and are problematic to engineering structures because of their tendency to heave during wet season and shrink during dry season (Mishra *et al*. 2008). The cement stabilization of the problematic soils is very important for many geotechnical engineering applications such as pavement structures, road- ways, building foundations, channel and reservoir linings, irrigation systems, water lines and sewer lines to avoid the damage due to the swelling action (heave) of the expensive soils or the settlement of the soft clays (Ismael, 2006). Cement treatment techniques have been of great interest for many years and have been developed across the world. When cement is added to soils in the presence of water, cation exchange begins to take place immediately after mixing. Clay particles are surrounded by a diffuse hydrous double layer which is altered by the ion exchange of calcium. This alters the density of the electrical charge around the clay particles and attracts them closer to each other to form flocculation. During the first stage, improvements occur immediately in soil plasticity, workability, swelling and permeability (Bell, 1976; Al-Rawas, 2002). The pozzolanic reaction takes place over a long period of time, between clay and cement kiln dust, during this process, the highly alkaline environment produced by the addition of lime makes dissolution of silica and alumina of the clay minerals and combination with the calcium produce new cementitous compounds, C-S-H, C-A-H, and C-A-S-H. So that the soil texture improves, increase the strength, reduce swell characteristics and decrease the soil permeability (Zaman, *et al*., 1992). Stabilization of clayey soil by using CKD decreased the voids with CKD addition; results in increasing the strength and the decrease in voids may result from a combination processes i.e., the hydration products developing early, this mentioned by (Sayah, 1993). The main goal of this study is to reduce swelling and to improve geotechnical properties of stabilized soils. To study the improvement of the pozzolanic reaction with curing time for various cement percentages for unconfined compressive strength test by XRD and SEM/EDAX tests on the best cement soil mixtures.

2. MATERIALS AND METHODS.

2.1. MATERIALS

2.1.1 Cement Kiln Dust (CKD): The cement kiln dust is by-product from Helwan cement plant and which consists of non-plastic fine grained materials having silt size grains, the chemical, mineralogical, and physical compositions of CKD varies from one plant to another, depending on raw material, type of kiln operation, dust collection method, and type of fuel used in the plant (Klemm, 1980).

2.1.2 Cement: This is the powdered material which tough adhesive qualities when combined with water (Labalm, 1983). Local Portland cement produced in Helwan factory was used in this research.

2.1.3 Swelling soil: Swelling soils are known to be found in different arid and semi-arid regions in Egypt, (e.g. Aswan, Edfu. Nasser city, Sinai, Assiut, New Valley, New Cities around Cairo and Toshka). The swelling soil in the research obtained from an area in the southeastern corner of the western desert of Egypt, named as Toshka area.

2.1.4 Soft clay: Soft clay is one of the problematic soils in Egypt, The soft clay in the research obtained from Sahl Al-Tinah area, located in North Sinai governorate. The very soft clay deposit in this area was formed during the recent periods in the form of marine deposits.

2.2. METHODS: The materials used in this group are (swelling soil, soft clay, CKD and cement). These materials were dried for 24 hours in oven at 70^0 CS and crushed to pass through sieve No. 40 before mixing, weighted, after that various percent of swelling soil and soft clay were mixed with constant ratio of CKD 20% (fresh mixtures), to determine atterberg limits (ASTM D4318, 2010), free swelling test (ECP 202/2-2001), CBR test and compaction test (AASHTO, T 99, 2010), then added small ratios of ordinary cement (6%, 9%, 12%) to that mixtures, cylindrical specimens were prepared and cured for 7, 14, 28, 90 days, to determine the unconfined compressive strength, with each percent of cement (after hardening).

Microstructure and mineralogy of the natural soils and the best mixtures before and after the treatment are measured. These tests were carried out in laboratories of soil mechanics and foundations and chemical laboratory of Construction Research Institute (CRI), National Water Research Center (NWRC). Housing and Building Research Center (HBRC) and National Research Center (NRC).

3. RESULTS AND DISCUSSION

3.1. Geotechnical Results.

3.1.1. Unconfined Compressive Strength Test: The unconfined compressive strength test was used to evaluate the strength performance and durability of stabilized clay soil, compressive strength is considered as one of the most popular methods used to evaluate the performance of soil stabilization (Yarbasi, *et al*., 2007). Many additives effect on the compressive strength such as cement and cement dust ratios.

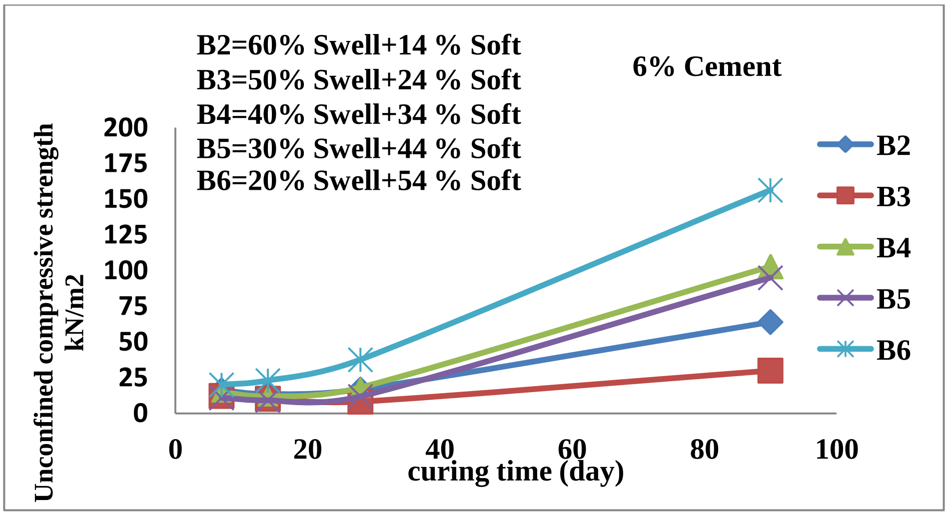


Figure (1): Effect of cement content on the compressive strength

Figure (1) shows that the relation between the unconfined compressive strength and the curing time of mixtures contains swelling soil, soft clay, and constant ratio of cement equal to 6% and constant ratio of CKD equal to 20%. The unconfined compressive strength increases at the curing time increase, where the compressive strength of the samples slightly increases until the 28 days curing time. After the 28 days curing time the rate of the increases of the compressive strength is very high. At the early stage (after 7 days curing time) the maximum value of compressive strength at mix B6 is (20) kN/m^2. The minimum value of compressive strength at mix B3 is (8.3) kN/m^2. At the late stage (after 90 days curing time) the maximum value of compressive strength at mix B6 is (156.3) kN/m^2. The minimum value of compressive strength at mix B3 is (30) kN/m^2. From the above figure we concluded that the compressive strength increases as the swelling soil decrease and the soft clay increase from (30 to156.3) kN/m^2.

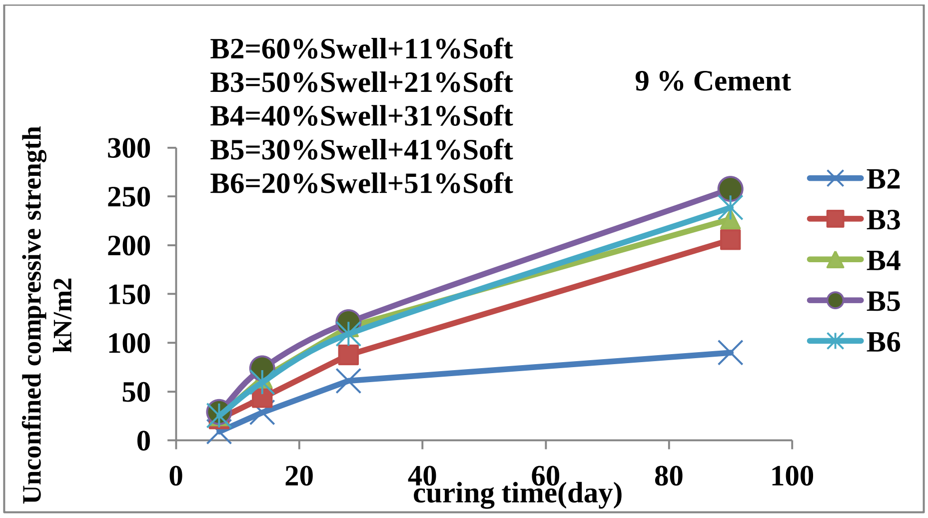


Figure (2): Effect of cement content on the compressive strength

Figure (2) shows that the relation between the unconfined compressive strength and the curing time of mixtures contains swelling soil, soft clay, constant ratio of cement equal to 9% and constant ratio of CKD equal to 20%. Unconfined compressive strength increases at the curing time increase, where the compressive strength of the samples slightly increases until the 28 days curing time. After the 28 days curing time the rate of the increases of the compressive strength is very high. At the early stage (after 7 days curing time) maximum value of compressive strength at mix B4 is (31.1) kN/m^2. Minimum value of compressive strength at mix B2 is (8.9) kN/m^2. At the late stage (after 90 days curing time) the maximum value of compressive strength at mix B5 is (257.6) kN/m^2. The minimum value of compressive strength at mix B2 is (89.9) kN/m^2. From above figure we concluded that the compressive strength increases as the swelling soil decrease and the soft clay gradually increases from (89.9 to 257.6) KN/m^2.

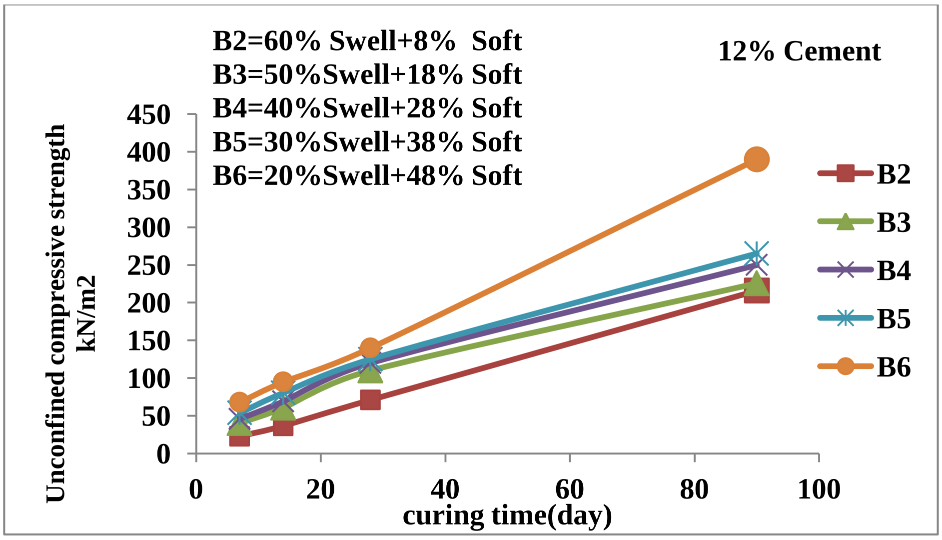


Figure (3): Effect of cement content on the compressive strength

Figure (3) shows that the relation between the unconfined compressive strength and the curing time of mixtures contains swelling soil, soft clay, constant ratio of cement equal to 12% and constant ratio of CKD equal to 20%.The unconfined compressive strength increases at the curing time increase, where the compressive strength of the samples slightly increases until the 28 days curing time. After the 28 days curing time the rate of the increases of the compressive strength is very high. At the early stage (after 7 days curing time) the maximum value of compressive strength at mix B6 is (73.7) kN/m^2. The minimum value of compressive strength at mix B2 is (22.7) kN/m^2. At the late stage (after 90 days curing time) the maximum value of compressive strength at mix B6 is (389.8) kN/m^2. The minimum value of compressive strength at mix B2 is (215.9) kN/m^2. From the above figure we concluded that the compressive strength increases as the swelling soil decrease and the soft clay increase from (215.9 to 389.8) kN/m^2.

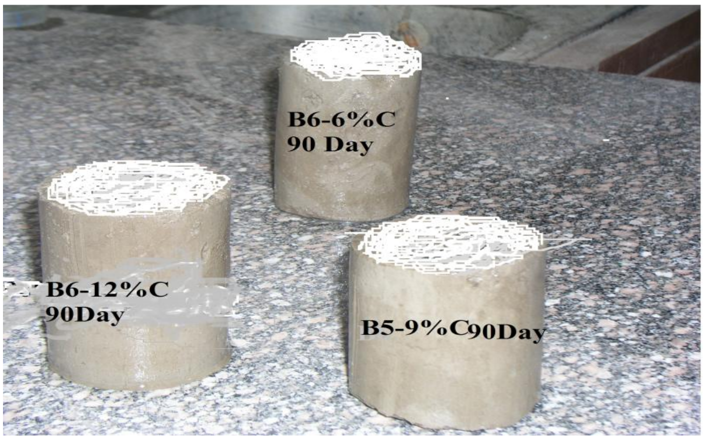


Figure (4): the stabilized samples before the unconfined compressive strength test

3.1.2. Compaction test results: This test used to get the maximum dry density and the corresponding optimum moisture content (OMC) of the various mixtures. The compaction tests were conducted in accordance with the (ASTM, D1557 2009).

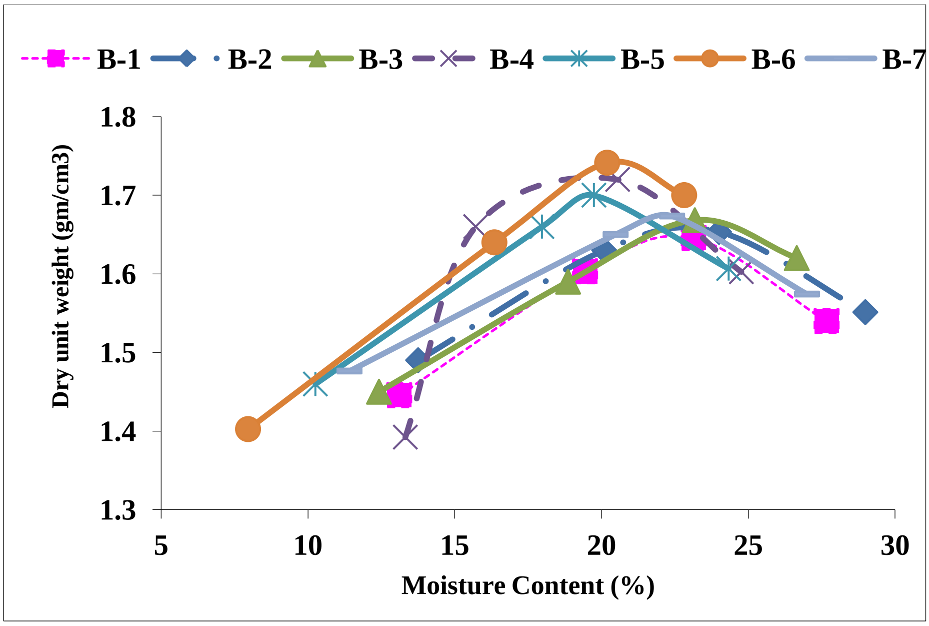


Figure (5): the modified proctor compaction curves for various mixtures.

Figure (5) shows the compaction curves of various mixtures. It illustrated the relation between the dry unit weights (gm/cm^3) and moisture content (%) of mixtures contains swelling soil, soft clay, and constant ratio of CKD equal to 20%. The maximum dry density is (1.74gm/cm^3) and the optimum moisture content is (20.19%) which represent by mix. (B6). The minimum dry density is (1.65gm/cm^3) and moisture content is (23.14%) which represent by mix. (B1). From the above figure we concluded that the dry density increases as the swelling ratio soil decrease and the soft clay ratio increase from (1.65 to1.74 gm/cm^3).

3.1.3. California Bearing Ratios (CBR) test results

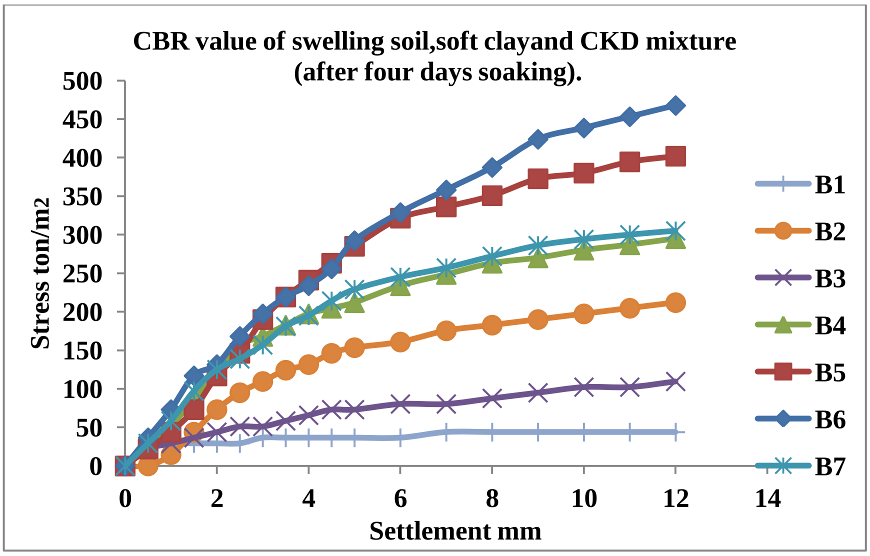


Figure (6): Relation between stress and settlement of various mixtures.

Figure (6) shows that the relation between settlement (mm) and the stress (kg /cm^2). This mixture contains swelling soil, soft clay and constant ratio of CKD equal to 20%. The CBR gradually increases with decreasing the swelling soil percent and increasing the soft clay percent up to 60%, over this ratio the CBR were decreased. The mixes B1,B2, B3 are slightly increases in CBR values (2.9,4.98, 5.12) respectively at settlement (2.5),(1.5) and (3) mm respectively, which is considered as poor to fair CBR value and use as subgrade (AASHTO soil classification system from ASTM M 145)**.**While the mixes,B4,B7 are increases in CBR values (14.6,14.6) at settlement (2.5),(2.5) mm respectively, which is considered as fair CBR value and use as sub-base (AASHTO soil classification system from ASTM M 145), the mixes B5,B6 are highly increases in CBR values (18.8,19.8) respectively at settlement (5) mm ,which is considered as fair CBR value and use as sub-base. Optimum value of CBR (19.85) was represented by mix B6. The lowest value of CBR (2.92) was represented by mix B1.From the above figure we concluded that the CBR values gradually increase with decreasing the swelling soil percent and increasing the soft clay percent from (2.92 to19.85) and due to increase the dry density to (1.74gm/cm^3).

3.1.4. Atterberg Limits and Free Swelling:

Table (1): Atterberg limits and free swelling results of various mixtures and natural soils

Mix.no	Mix- ratios Swell	Soft	Dust	Liquid limit	Plastic limit	Plasticity Index	Free Swell.
	%			%	%	%	%
B1	70	10	20	60.4	41.2	19.2	50
B2	60	20	20	58.7	41.2	17.5	46.7
B3	50	30	20	55.4	38.7	16.7	46.6
B4	40	40	20	51.9	38.5	14.3	46
B5	30	50	20	51.8	35.4	14.0	30
B6	20	60	20	49.9	36.3	13.6	20
B7	10	70	20	49.4	36.3	13.1	20
Swelling clay				85	32	51	125
Soft clay				55	24	37	10

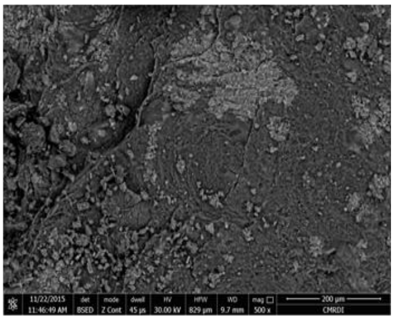
The liquid and plastic limits were determined in accordance with the (ASTM, D4318 1984).The liquid limit of the soft clay is 55% and swelling clay is 85%, plastic limit of the soft clay is 24% and swelling clay is 32%, i.e. the plasticity index of soft clay is 37% and swelling clay is 51%. The free swelling of soft clay is 10% and swelling clay is 125%, as showen in table (1).The liquid and plastic limits of the various mixtures were determined to assess their behavior and compare it to the natural soil. The values of the liquid limit, plastic limit and free swelling of the various mixtures change in all mixtures at constant ratio of cement kiln dust 20%. This mixture contains swelling soil, soft clay and constant ratio of CKD equal to 20%. The values of plasticity properties slightly decrease with gradually increase of soft clay percent and gradually decrease of swelling clay percent in all mixtures and the reverse is true. The liquid limit decrease from (60.4% to 49.4%), the plasticity index decrease from (19.2 % to13.1%) and free swelling decrease from (50% to 20%). From the above table we concluded that the plasticity properties decrease with decrease of swelling soil and increase of soft clay. Also free swelling decrease with decrease of swelling soil and increase of soft clay.

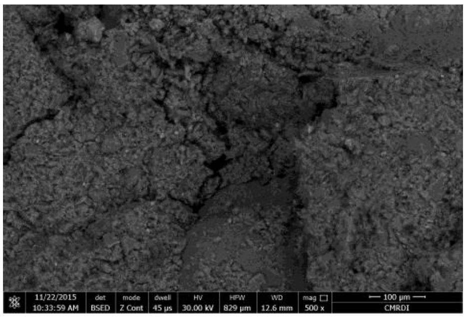
3.2 Mineralogical and Microstructural analyses of stabilized soil: The clay mineral contents were investigated by using (XRD), where the minerals of the raw materials can usually identified from the diffraction lines, although it is not possible to determine the exact proportion of each mineral in a mixture. Interpretation of the diffraction patterns are based on fact that each crystalline material has its own characteristic atomic structure which diffracts

X-ray in a characteristic pattern (Barr, and Klinowski 1995).

The natural soils and the best mixtures contains cement ratios (6%, 9%, 12%) that treated at (7, 90) days curing time, are examined by using XRD and SEM. Microstructure refers to the shape, size and arrangement of soil aggregates and pores .That is generally observed at a rather low magnification. The surface horizon generally has crumb and granular microstructure whereas the subsoil horizons have angular to sub angular blocky microstructure.

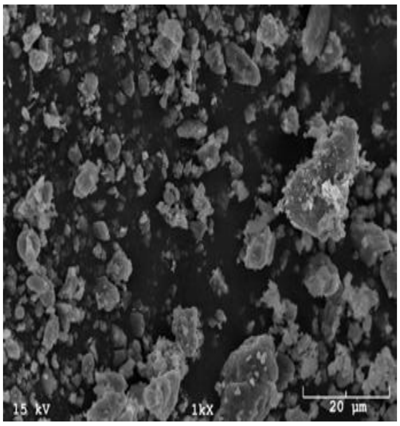
3.2.1 Before Treatment:

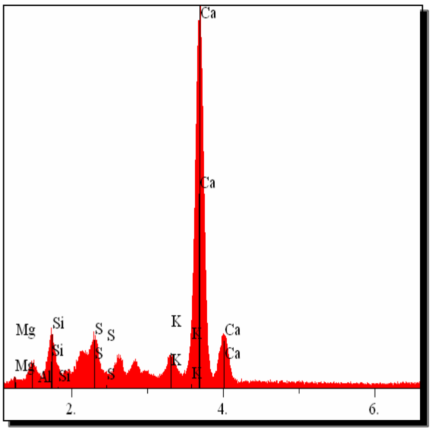




(A) **(B)**

Figure (7A): SEM of Natural soil (Swelling clay) **(B)** SEM of Natural Soil (Soft clay)





(C) SEM/EDAX of CKD Powder

The XRD analyses of the natural swelling soil under investigation shows the presence of varying amounts of several minerals (Quartz, Calcite and Hematite) and the clay minerals are (69%) montmorillonite, (30%) kaolinite, 1% illite. The soluble salts of the studied soil including sulfates and chlorides are 0.620% and 0.745% respectively. The XRD of the natural soft clay shows non-clay mineral (halite and quartz) and clay minerals are (49%) montmorillonite, (24%) illite, and (27%) Kaolinite. The soluble salt of the studied soil including sulfates and chlorides are 1.9% and 7.6% respectively. The SEM/EDAX of raw CKD powder is more complex compounds. The EDAX results indicated presence of Ca, Si, S, Mg and K elements. Figure (7C) shows the scanning electron micrographs (SEM) for CKD it shows particles with poorly defined shape and the particle shapes were found to be angular with non-uniformed shapes. The surfaces were rough with sharp corners. Distribution grain size of cement was within a range of 5-20 μm. The heights of the peaks were used as a qualitative measure rather than a quantitative measure of different crystal phases. Figure (7A) illustrated the micrograph (SEM) of the natural swelling soil which contains small pores and denser than natural soft clay, it showed flaky arrangements of clay particles as matrix between detrital fine grains. The texture consists of many sheet-like particles. The flaky and plate-like particles could be identified as Montmorillonite and Kaolinite. The micrographic observation for swelling clay indicates presence of spherical particles in abundance, mixed fabric with certain amount of mineral aggregations. Figure (7B) illustrated the micrograph (SEM) of the natural soft clay soil which contains large pores, less dense than natural swelling soil and semi-regular aggregation. The texture consists of many sheet-like particles and mixed fabric with certain amount of mineral aggregations, could be identified as Montmorillonite and Kaolinite.

3.2.2 After Treatment:

3.2.2.1 Mineralogical analyses after 7 days curing time:

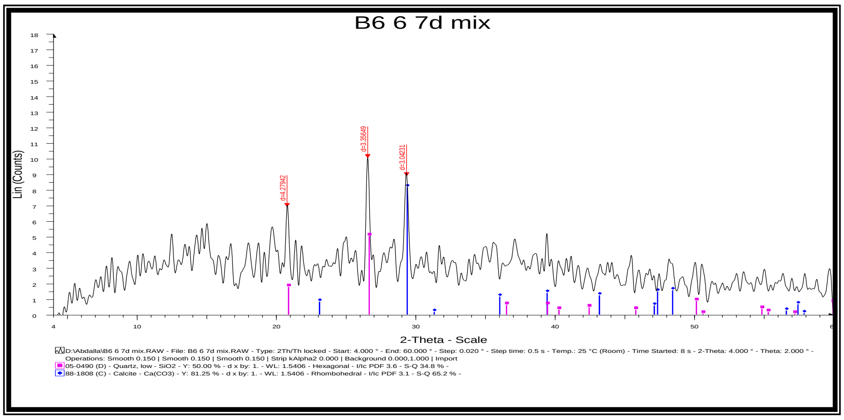


Figure (8): Spectrum XRD of mixture B6-6% cement after 7dayes curing time.

Figure (8) showed the (XRD) of mixture B6-6% cement after 7dayes curing time). From previous patterns, there are many peaks which are related to different compounds. These compounds can be classified into two main elements as (SiO_2) quartz and (Ca CO_3) calcite.

Table (2): Summary of distinctive feature of different components in mixture.

phase	Chemical Composition	Polymorphs	PDF Card	Content %	Distinct features of diffractograms
Quartz-Low	**SiO_2**	**Hexagonal**	**05 -0490**	**34.8%**	**Strong peaks between (26-27)º and at(21)º**
Calcite	**$CaCO_3$**	**Rhombohedral**	**88 -1808**	**65.2%**	**Strong peaks between(29-30)º, between(47-49)º**

This figure showed that when studied the reaction products of the (mix B6-6% cement after 7dayes curing time), it is observed that the clay mineral are transferred to non-clay mineral, as showen in table (2). The content of quartz SiO_2 is 34.8 % and the content of calcite Ca CO_3 minerals is 62.2% which found in major amounts as non-clay components, which is forms cementitous products, these non-clay minerals has a more complex crystalline structure.

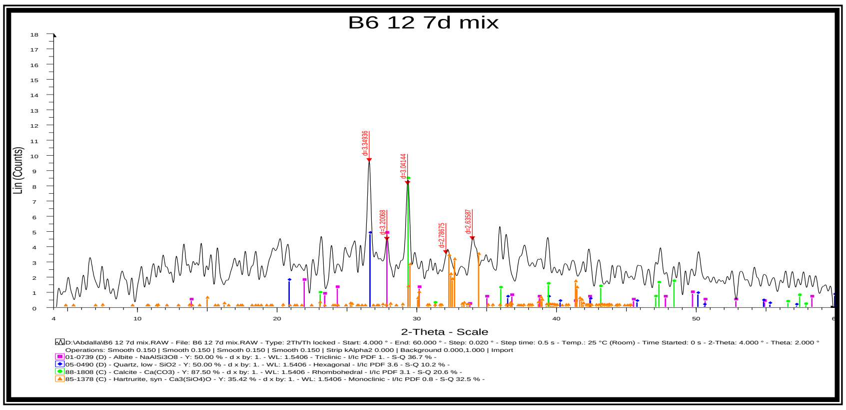


Figure (9): Spectrum XRD of mix B6-12% cement after 7dayes curing time.

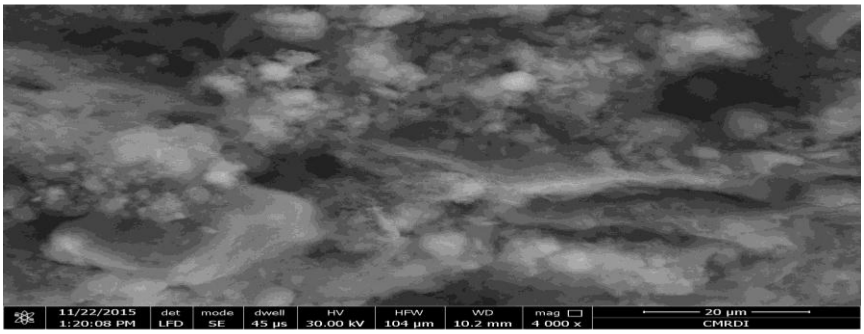
Figure (9) showed the (XRD) of the mixture B6-12 % cement after 7dayes curing time. From the following patterns, there are many peaks which are related to different compounds. This compounds can be classified into four main elements as summarized in table (3)This elements as $NaAlSi_3O_8$ Albite, SiO_2 quartz, Ca CO_3 Calcite, Ca_3 (SiO_4) O Hartrurite.

Table (3): Summary of distinctive features of different component in mixture.

phase	Chemical Composition	Polymorphs	PDF Card	Content %	Distinct features of diffractograms
Albite	**$NaAlSi_3O_8$**	**Triclinic**	**01-0739**	**36.7**	
Quartz-Low	**SiO2**	**Hexagonal**	**05-0490**	**10.2**	**Strong peaks between (26-27)º and at(21)º**
Calcite	**$CaCO_3$**	**Rhombohedral**	**88-1808**	**20.6**	**Strong peaks between(29-30)º and between(47-49)º**
Hartrurite	**$Ca_3(SiO_4)O$**	**Monoclinic**	**85-1378**	**32.5%**	

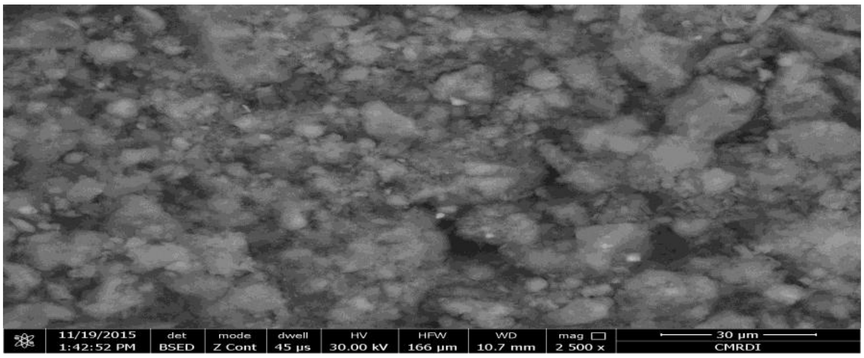
Figure (9) showed that when studied the reaction products of the mixture B6-12 % cement after 7dayes curing time, it is observed that the clay mineral are transferred to non-clay mineral, as showen in table (3). The content of quartz (SiO_2) is 10.2 %, calcite $CaCO_3$ mineral is 20.6 %, albite ($NaAlSi_3O_8$) is 36.7% and Hartrurite is 32.5%. Which is forms cementitous product, these non-clay minerals has a more complex crystalline structure.

3.2.2.2 Microstructural Changes after 7 days curing time:



(A)

Figure(10): SEM of mix B6 12%cement at7days cured



(B)

Figure(10): SEM of mix B6 6%cement at 7 days cured.

Figure (10A) illustrated the micrograph (SEM) of the stabilized soil with 20% CKD of mixture B6 12%cement at 7days curing time. The micrograph showed connected pores, the texture more densed, ettringite is few in the matrix, and it is observed that the pore spaces were covered by the cement gel (hydrated cement) and it showed crumbs of floccules with porous nature and cementitous compounds, calcium aluminum hydrate (C-A-H) and calcium silicate hydrate (C-S-H), coating the relics of the clay particles. The hydration products in the pores are clearly seen and the soil-cement clusters tend to be larger because of the growth of cementitous products over time. The cementation contributed to the strong inter-particles bonds that can offer greater strength of the stabilized soil (Wong, *et al.,* 2013). Figure (10B) illustrated the micrograph SEM of the stabilized soil with 20% CKD of (mix B6 6% cement at 7 days curing time).The micrograph showed cementitous compounds (due to pozzolanic reaction) coated and joined the soil and the cement kiln .The pores were partially filled with the cementitous compound and were relatively reduced. It illustrated large pores and separated, ettringite is few in the matrix, contain connected pores and the texture less dense that led to weak strength.

<u>3.2.2.3 Microstructural and Mineralogical changes after 90 days curing:</u>

Figure (11A) shows the SEM photograph of (mix B6 12% cement), it shows smooth dense surface and decreasing in the voids and gaps size which has Avery good effect on improving the mechanical properties. It illustrates the formation of more new cementitous compounds after long-term curing (spiny crystals) as a result of the pozzolanic reaction coating the aggregates and the cement dust particles and filling the pore spaces (voids) between the flocs.

The mechanical behavior of the stabilized soil had a brittle behavior due to a formation of cementitous compound. The formed cementitous compounds (as a result of the chemical reactions between the silica and the alumina and the additives) reduced the volume of the void spaces and joined the soil particles (Ismael, 2006). Pozzolanic reaction

$Ca\ (OH)_2 + H_4\ SiO_4 \rightarrow Ca^{2+} + H_2\ (Si_4)^{2-} + H_2O \rightarrow CaH_2\ SiO_4.2H_2O$

CH +SH → C-S -H Calcium silicate hydrate

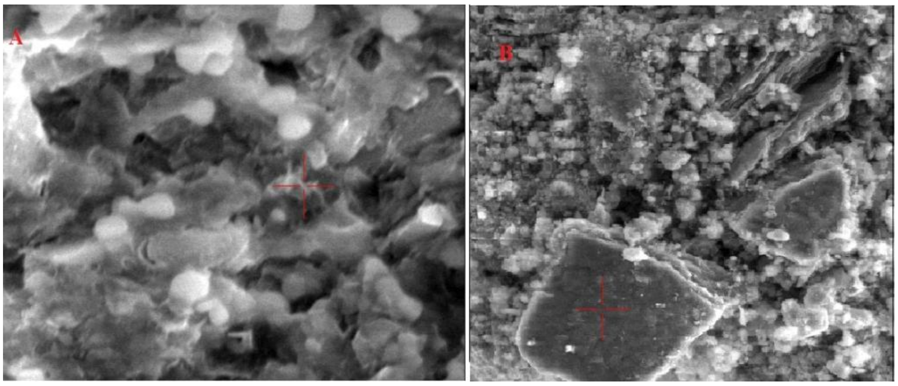
Ca^{++}_{+} 2OH $+Al_2O_3$ → C-A-H Calcium aluminum hydrate

(Alumina) (Fibrous)

Figure (12A) shows the analysis pattern of X- ray spectrum of SEM of (mix B6 12% cement). It can be noted that, the main elements in this mixture are Si, Ca and Al, whereas Cl, Fe, K and S are barely noted. Ca/Si atomic weight ratio in the treated material is estimated and found to be 0.49. The presences of Ca and Si elements are representative to Ca (OH) 2 and C-S-H present in the specimen. The decrease in this ratio was due to the increase in silica content because of the cement kiln dust and cement added. It could also be observed that the $Ca\ (OH)_2$ content decreased and C-S-H gel increased. This could be as a result of consumption of free $Ca\ (OH)_2$ by CK D and deposits within the pore system leading to a more dense structure.

Figure (11B) shows the SEM photograph of (mix B6 6% cement). It shows that the surface feature shows more folds and pores, it contain small cracks in general view, contains connected pores, lamellar plate's structure and fractures this led to decrease of compressive strength. Also observed that the pore spaces were covered by the cement gel (hydrated cement). The formation of the cementitous compounds including calcium hydroxide around the clay particles is apparent. It can also be observed that these compounds formed an interwoven fabric type structure around the clay particles, These observations indicate that a good mixing between soil and cement kiln dust-cement additives, forming of a dense treated soil mixture with voids being filled with fibrous pozzalonic material and the hardening effect was mainly attributed to cement hydration in the early stage in combination with pozzolanic reactions at long term.

Figure (12B) shows the analysis pattern of X- ray spectrum of SEM of (mix B6 6% cement). It can be noted that, the dominating peaks in the EDAX point to a considerable amount of silica (20.26%), alumina (11.02%) and calcium (1.39%) in the treated area, which might have come from both cement kiln dust and cement binders. Ca/Si atomic weight ratio in the treated materials is estimated and found to be 0.07%. The presences of Ca and Si elements are representative to Ca (OH) 2 and CSH present in the specimen. The decrease in this ratio was due to the increase in silica content because of the cement kiln dust and cement added. That means more leaching of Ca $(OH)_2$ and more generation of C-S-H which is responsible for improving hydration process



(A) **(B)**

Figure (11A): SEM of mix B6 12% cement. **(B)** SEM of mix B6 6% cement.

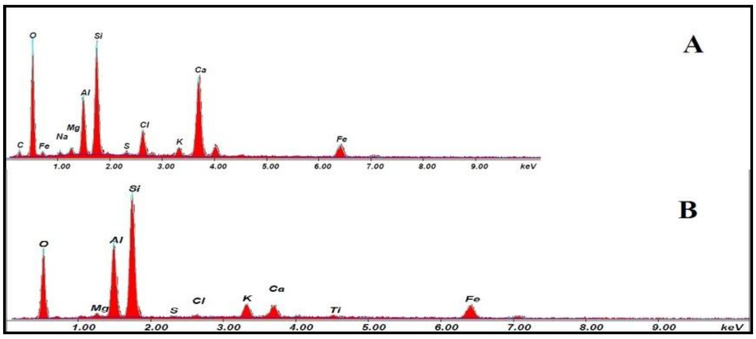


Figure (12A): EDEX of mix B6 12% cement, **(B)** EDEX of mix B6 6% cement

4. CONCLUSION

The following points can be concluded from the results of this work:

1- The unconfined compressive strength at (6%, 9%, 12%) cement increases as the swelling soil decrease and the soft clay increase from (30 to156.3), (89.9 to 257.6), (215.9 to 389.8) KN/m^2 respectively at the late stage after 90 days curing time and the maximum value of UCCS are represent by mixes (B6, B5, B6) is (156.3, 257.6, and 389.8) KN/m^2 respectively. Generally, the UCCS increases as the curing time increases.

2-The CBR values gradually increases with decreasing the swelling soil percent and increasing the soft clay percent up to 60%, over this ratio the CBR were decreased. The optimum value of CBR is (19.85) represented by mix B6 and the CBR values gradually increases from (2.92 to19.85) due to increases the dry density to ($1.74gm/cm^3$).

3-The plasticity properties and free swelling of the various mixtures changes in all mixtures at constant ratio of CKD (20%) and decreasing with decrease of swelling soil and increase of soft clay.

4- The plasticity properties decrease with increase of the CBR values of the mixtures. To get higher CBR, higher dry density, and low water content.

5-Chloride ion present in soft clay, CKD and cement are cause decrease in repulsive forces between clay particles led to flocculated structure with some cementation that should have been responsible for decreasing free swell. The reason of such tendency might be the reduction in diffuse double layer thickness due to ion exchange, causing flocculation.

6- The presences of Ca and Si elements in SEM/EDS analysis of the best mixture are representative to Ca (OH) 2 and C-S-H present in the specimen. The decrease in ca/si ratio was due to the increase in silica content because of additives. Then the $Ca(OH)_2$ content decreased and C-S-H gel increased. This due to consumption of free $Ca(OH)_2$ by CKD and deposits within the pore system leading to a more dense structure.

7- The SEM photographs observations agreed well with results from unconfined compressive strength tests.

8-The new minerals which formed in cement treated soil, are investigated by XRD analyses is responsible for the improvement in the strength properties.

REFERENCES

AASHTO, T 208, (2010). "Standard Method of Test for Unconfined Compressive Strength of Cohesive Soil," Single User Digital Publication, American Association of State Highway and Transportation, Washington.

AASHTO, T 99, (2010). "Standard Method of Test for Moisture-density relation of Soils Using a 2.5kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop," Single User Digital Publi- cation, American Association of State Highway and Transportation Officials, Washington DC.

Al-Rawas, A. A. (2002). Microfabric and mineralogical studies on the stabilization of an expansive soil using cement by-pass dust and some types of slags. Canadian Geotechnical Journal, 39(5), 1150-1167

Al-Refeai, T.O (2000). "Stabilization Characteristics of Cement Kiln Dust," Geoengineering in Arid Lands, 133-137.

ASTM D4318 (2010). Standard test methods for liquid limit, plastic limit and plasticity index of soils. Standard Annual Book of ASTM, USA. 04-08, 37- 42.

Barr, T. L., Klinowski, J (1995). X-ray photoelectron studies of kaolinite and montmorillonite: Pergamon, 95(46), 1391-1395.

Bell, F.G., (1976). "The influence of the mineral contents of clays on their stabilization by cement", Bulletin of the Association of Engineering Geologists, 13(2), 267-278.

Egyptian Code, "Egyptian Code of Soil Mechanics" (2001) .Foundations carrying out and Designation, Part 2, Laboratory Tests, 6th Edition.

Ismael, H. A. H., (2006). “Treatment and improvement of the Geotechnical Properties of Soft Fine-grained Soils Using Chemical Stabilization,” Ph.D. Thesis, Thematisch-Naturwissenschaftlich-Technischen Fakultät der Martin-Luther-Universitat Halle-Wittenberg, pp.65-68.

Klemm, W. A. (1980).Cement Kiln Dust Utilization, Martin Marietta Laboratories Report MML TR 80-12, Baltimore, Maryland, U.S.A.pp.7-12.

Labalm, O., (1983) cement engineers' handbook." Bauveriag GmbH. 3rd ed., 113-120.

Ministry of housing and infrastructures (2009). "Egyptian code for soil mechanics, foundation design and construction, ECP 202/2-2001.Lab. tests.

Mishra, A.K., Dhawan S., Rao, S.M., (2008). Analysis of Swelling and Shrinkage Behavior of Compacted Clays, Geotechnical and Geological Engineering, 26 (3), 289-298.

Sayah, A.I. (1993). Stabilization of expansive clay using cement kiln dust, M.Sc. Thesis, Graduate School, University of Oklahoma, Norman, Oklahoma, U.S.A. 55-62.

Show, Y., Tay, H., and Goh, C., (2003). Reuse of incinerator fly ash in soft soil stabilization, Journal of Materials in Civil Engineering, 15(4) 1254-1260.

Sivapullaiah, P. V., (1996). Pozzolanic stabilization of expansive soils; recent advances in characterization and treatment Edited by Ali- Rawas, A.A. and Goosen, M. F. A, Taylor and Francis Group, London.

Wong, L.S., Hashim, R., and Ali, F. (2013). "Improved strength and reduced permeability of stabilized peat: focus on application of kaolin as a pozzolanic additive." Construction and Building Materials, 40(10), 783-792.

Yarbasi, N., Kalkan, E., & Akbulut, (2007). Modification of geotechnical properties, as influenced by freeze thaw, of granular soil with waste additive. Journal of Cold Regions Science and Technology, 48(1), 44-54.

Zaman, M., Laguros, J.G. and Sayah, A., (1992). "Soil Stabilization Using Cement Kiln Dust. Proc., 7th International Conference on Expansive Soils, Dallas, 1, 347- 351.

تحسين خصائص التربه الانتفاشيه باستخدام غبار الاسمنت

[٢]

سمير أحمد عوض[١]– محيى الدين محمد المشد[٢]– سامى سعيد زاهر[٢]
١) قسم الجيولوجيا، كلية العلوم، جامعه عين شمس ٢) معهد بحوث الانشاءات، المركز القومي لبحوث المياه، وزاره الموارد المائيه والري

المستخلص

يهدف هذا البحث الي دراسه استخدام بعض المخلفات الصلبه الصناعيه لتحسين سلوك التربه ذات المشاكل مثل التربه الانتفاشيه والتربه الرخوه وحيث ان هذه التربه لا يصلح التاسيس عليها بسبب ضعف تحملها وانتفاشها ولذلك في هذا البحث نحاول استخدام غبار الاسمنت الناتج من صناعه الاسمنت في تحسين هذه التربه .وحيث ان غبار الاسمنت له تاثيرسلبي علي البيئه ويسبب اضرارا صحيه لكل الكائنات المحيطه بالمصانع وهو مخلف يماثل في تركيبه الكيميائي الاسمنت الا انه يحتوي علي نسبه عاليه من كلوريدات وكبريتات القلويات، لذلك تم خلط هذه التربه بنسب مختلفه مع نسبه ثابته ٢٠% من غبار الاسمنت ونسبه صغيره من الاسمنت العادي ٦% ،٩% و١٢%. في هذه الدراسه تم استخدام تقنيات عاليه مثل حيود الاشعه السينيه وميكروسكوب التصوير الالكتروني للتعرف علي التغيرات المعدنيه والتركيب النسيجي الدقيق الداخلي للخلطات قبل وبعد المعالجه بالاضافه الي الاختبارات الجيوتقنيه مثل حدوداتربرج، الدمك القياسي، ومقاومه الضغط غير المحصور واختبار نسبه تحمل كاليفورنيا واختبارالانتفاش الحر. واظهرت النتائج ان الكثافه الجافه تزيد من(١,٦٥–١,٧٤جرام | سم٣) وكذلك محتوي الرطوبه يصل الي (٢٠,١٩%) وخاصه عندما تقل نسب التربه الانتفاشيه وتزيد نسب التربه الرخوه في كل الخلطات. ايضا مقاومه الضغط غير المحصورتزيد عندما تقل التربه الانتفاشيه وتزيد التربه الرخوه من (٣٠–١٥٦,٣) كيلونيوتن|م٢ عند المعالجه في المياه (٩٠ يوم ونسبه اسمنت ٦%) ،كذلك تزيد من (٨٩,٩–٢٥٧,٦) كيلونيوتن|م٢ عند المعالجه في المياه (٩٠ يوم ونسبه اسمنت٩%)، وتزيد من (٢١٥,٩–٣٨٩,٨) كيلونيوتن|م٢ عند المعالجه في المياه (٩٠ يوم ونسبه اسمنت١٢%). ايضا قيم حد السيوله واللدونه ومعامل اللدونه تقل تدريجيا مع زياده نسبه الطين الرخو وقله نسبه التربه الانتفاشيه في كل الخلطات، وايضا نسبه الانتفاش الحر تقل من (٥٠%–٢٠%) .ايضا تحليلات حيود الاشعه السينيه والتصوير الالكتروني بعد المعالجه اظهرت ان كل معادن الطين تحولت الي مركبات اسمنتيه مثل سليكات الكالسيوم المتادرته والومينات الكالسيوم

المتادرته والتي تعتبر مركبات ذات تركيب بللورى أكثر تعقيدا خاصة مع زيادة زمن المعالجه ، وبهذا يمكن استخدام غبار الأسمنت فى تثبيت الترىه وتحسينها وحماية البيئه من ملوثاتها.