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Stabilization Marl Clay by Karak Ash

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Abstract: Soil stabilization has been practiced for quite some time by mixing additives, such as cement, lime and fly ash to the soil to increase its strength. The impact of cyclic wetting and drying on compressive strength behaviour of ash stabilized marl clayey soils has been investigated. Karak ash was added to marl clayey soils at ranges of 0-100%. Specimens were cured for 7, 28, 56 and 365 days after which they were tested for unconfined compressive tests. On the other hand, the residual compressive strength increases significantly compared to initial compressive strength. Treatment with Karak ash was found to be an effective option for improvement of soil properties, based on the testing conducted as a part of this research. Strength are improved and plasticity and swell potential were substantially reduced.

Key words: Karak ash · Lime · Marl clay · Wet-dry cycle · Strength · Swelling and Soil stabilization

INTRODUCTION

Subgrade soils are an essential component of pavement structures and inadequate subgrade performance is the cause of many premature pavement failures. Poor subgrade soil conditions can reduce pavement life which is the case in Jordanian road networks. Unsaturated clay subgrades in particular may provide inadequate support, particularly when saturated. This is common case in Jordan because the soil is always unsaturated due to long summer. Soils with significant plasticity may also shrink and swell substantially with changes in moisture conditions. These changes in volume can cause the pavement to shift or heave with changes in moisture content and may cause a reduction in the density and strength of the subgrade, accelerating pavement deterioration. Therefore, the mechanical stabilization is not enough. There is a substantial history of use of soil stabilization admixtures but is not used in Jordan to improve poor subgrade soil performance by controlling volume change and increasing strength.

Soils may be improved through the addition of chemical or cementitious additives. The later can be used with a variety of soils to help improve their native engineering properties. The effectiveness of these additives depends on the soil treated and the amount of additive used. These additives range from waste products such as Karak ash to manufactured materials and include lime, class C fly ash, Portland cement, cement kiln dust from pre-calciner and long kiln processes and proprietary chemical stabilizers. Recently class C fly ash has been used as an economical alternative to improve subgrade performance rather than Lime and cement.

About 52 billion tons of the bituminous oil shale deposits are widely distributed in Jordan as confirmed by the successive geological surveys carried out the Natural Resources Authority in Jordan [1]. These deposits are of Cretaceous age, but vary in their organic content, thickness, average oil content and overburden thicknesses. Karak ash are produced from bituminous oil shale deposits in Karak (south of capital Amman/Jordan). The benefits of Karak ash which is found in this work by reducing volume change and increase strength. Several researchers have been found similar result such as [2-5].

The amount of additives should be examined to improve and modified the soil without adverse effect. Many laboratory test that conducted on lime showed stabilization with an inadequate amount of lime could yield improvements in soil behavior that were non-permanent [6]. Laboratory research also showed some evidence that the plasticity of fly ash stabilized soils can also revert to native levels with leaching [7]. However, stabilization soils by fly ash performed well in the field after a period of two years [8].

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Study Aim: This study was conducted with the following objectives in mind. First object is to confirm that introduction of Karak fly ash provides a statistically significant improvement in soil properties as compared with untreated subgrades. Second object is to quantify the improvement in subgrade properties achieved through the use of Karak ash. Third object is to determine whether there is a deterioration of the Karak ash treated subgrade over time. A series of tests were conducted in the laboratory and on existing treated soil to evaluate the performance of Karak ash (i.e. the time is one year). Laboratory tests were conducted on clay marl soils and included Atterberg limits, CBR, swelling potential and strength.

Characterization of the Karak Bituminous Limestone and Ash: Fly ash used in stabilization of poor subgrade and was also reported in stabilization of recycled pavement material and road surface gravel [9]. The Karak ash was obtained by direct combustion of Karak bituminous limestone at a temperature of (900-1000) °C in this work. The sample was allowed to cool down to the ambient temperature and then was ground under dry conditions to obtain the possible minimum grain size. Small ball mills and Los Angles machine were used. Ash could be the solid waste product of possible utilization of the Karak bituminous limestone. The chemical properties of Karak ash are summarized in Table 1.

The combusted bituminous rocks in Karak/ Jordan have indicated the presence of two groups of minerals; high temperature which is equivalent to clinker cement [10] and low temperature which is similar to the hydrated cement products [11]. The low temperature mineral group has a similar composition to the hydrated cement products and has been precipitated from high alkaline circulating water (pH > 12.5). This naturally occurring alkaline water is analogous to the cement percolating water [10].

Table 1: Classification of class C and F compared with Karak ash (Analysis was done using XRF technique) [2]

	Ferguson [2]		
Oxide%	Class C ash	Class F ash	Karak ash
SiO_2 %	54.9	39.9	33.82
$Al_2 O_3$ %	25.8	16.7	3.25
Fe_2O_3 %	6.9	5.8	1.44
CaO %	8.7	24.3	45.84
MgO %	1.8	4.6	2.47
SO_3	0.6	3.3	5.71

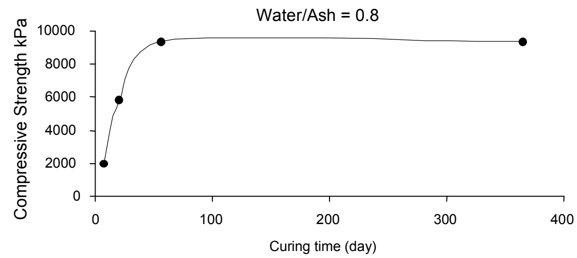

Fig. 1: Compressive strength of ash mortar sample versus curing period

According to ASTM standards [9], the ash samples have a lower pozzolanic content than both classes F and class C ash. The Karak ash has a very high CaO content relative to the ASTM classification. This indicates that the ash can be used efficiently in some proper aspects other than that indicated for both fly ashes of type F or type C in the international standards. The Karak ash is not complying with the classification proposed in Table (1). This leads to the decision that ash samples have a unique chemical composition which is characterized by a very high CaO.

Sampling and testing procedures are carried out following ASTM for testing compressive strength of hydraulic cement sand mortar [12]. All standard testing for strength determination of ash as a self cementing material has shown a high stability. No minor features of disintegration or disturbance of the prepared samples during the curing stage in water at normal ambient temperature (25-30)°C are observed. This reflects the opposite behavior of normal soils that could not sustain under saturation conditions. On the other hand, ash behaved as cementaceous material that has the possibility to gain strength under normal curing time and conditions as the other different types of cements. This is confirmed through the compressive strength results of standard 5x 5x 5 cm cubic samples. Compressive strength results at 7, 28, 56 and 365 days is presented in Figure (1). The specific gravity of ash is equal to 2.49. Standard Proctor test shows that the maximum dry density- moisture relationship of the ash sample revealed that the average maximum density is 12.8 kN/m^3 at optimum moisture content of 34.7%.

It is clear that from Figure (1) as the curing period increases the strength increases. The Karak ash is similar to a great extent to the Portland cement [1]. The ash and Portland cement are essentially composed of lime (CaO), Silica (SiO_2) and alumina (Al_2O_3) which are present at higher concentrations in the Portland cement and react with CaO at about 1425°C to form alite. Heat treatment of the bituminous rocks and Portland cement raw material involves dehydration, thermal decomposition of clay minerals (300-650°C), decomposition of calcite (greater than 800°C), the formation of belite (C_2S), tricalcium aluminates (C_3A) and tetracalcium alumina ferrite (C_4AF). The liquid phase and sintering at about 1425°C form alite (C_3S) which is responsible for the strength of concrete.

Karak bituminous limestone ash has revealed a self cementaceous behavior for the various prepared samples. The sample for the objectives of this work, has been combusted at 950°C. The development of the self cementaceous properties and strength are controlled by the temperature of combustion of the bituminous limestone, the lime content and the curing period. Ash sample is essentially composed of CaO. The variable CaO values are the result of LOI variation. The bulk density of these rock is of (19-20) kN/m^3. Their color are dark gray to black in color and its specific gravity is of (2.38-2.41). The ash samples are characterized as non plastic material.

X-ray fluorescence results indicate that the Karak bituminous rocks are dominated by calcite 20%-80%, Quartz 10%-40%, kaolinite 5-10%, apatite 4-14% and dolomite 2-3.6%. Minor minerals (around 5%), as feldspar, pyrite, goethite, gypsum, opal and muscovite are also present [1, 13, 14]. The rock is essentially composed of CaO, SiO_2, Al_2O_3 and Fe_2O_3.

Laboratory Testing on Marl Clay: Clay marl soil was selected for laboratory testing with Karak ash contents of 10%, 15% and 20%. Soils were classified as MH according to ASTM [15]. Also, as A-7 according to AASHTO and the group index (GI=21.15) which is considered a poor subgrade. The clay marl soils from Karak city (south of Amman capital of Jordan) at 1.5 meters depth. The marl is yellowish in color. The soils were evaluated for strength, Atterberg limits, swell potential and CBR. The XRD analyses of the clayey marl sample has shown that quartz (SiO_2) and calcite ($CaCO_3$) are the major components. Dolomite, kaolinite and smectites are also present. The chemical composition of the parent soil samples is given in Table (2).

Following ASTM standards [16, 17], the physical properties of the clayey marl are summarized in Table (3). The high liquid limit indicates a high exposure to moisture sensitivity due to the presence of high percentage of the clay fraction. This result reveals the cause of problems exhibited by this soil as a subgrade material.

Table 2: Chemical composition of clayey marl (L.O.I = 7.5%,* ICP technique)

Oxide	Clayey marl
SiO_2 %	17.52
Al_2O_3 %	5.92
Fe_2O_3 %	1.72
CaO %	32.30
MgO %	3.10
MnO %	0.02
TiO_2 %	0.30
K_2O %	0.90
P_2O_5 %	0.12

Table 3: Physical and mechanical properties of clayey marl

Parameter	Clayey marl
pH	8.10
Group Index (GI)	21.15
Specific gravity	2.65
Liquid limit (LL)	44.00
Plasticity index (PI)	23.00
Passing #200%	88.00
Clay fraction %	80.00

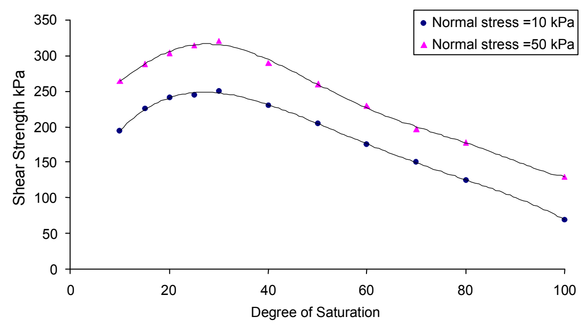

Fig. 2: Shear strength versus degree of saturation for clay marl soil

Figure (2) illustrated the result of many direct shear tests that have been conducted on native sample at maximum dry density and different degrees of saturation. Figure (2) shows the effect of degree of saturation on the shear strength to native sample (clay marl soil). The strength drops dramatically as the saturation exceed 40% for untreated soil. This means that the compacted unsaturated soil is sensitive to any change in water content (seasonal changing). The strength increases as the normal stress increases and as the degree of saturation increases up to 35 %. Figure (2) proves that the mechanical stabilization is not enough.

Testing on Clay Marl and Ash Mixture: Class C fly ash has been shown to improve the strength and modulus of subgrade soils through laboratory testing by several researchers [2, 4, 5]. Similar results were obtained for the soils evaluated as a part of this research. Strength gains of the order of 100-300% with the addition of fly ash were recorded. The marl clay soil was evaluated with 0%, 10%, 15% and 20% Karak ash by weight. Samples were mixed with a range of water contents and compacted in accordance with ASTM [18] and tested for strength in accordance with ASTM [19]. A delay time of 1 h was included between mixing and compaction of fly ash treated samples to simulate construction practice. Soil samples were extruded and cured for a 28-day, 56 days and 365 days period in a moisture room.

Atterberg Limits: Changes in the plasticity index was also evaluated. Addition of Karak ash caused some reduction in the plasticity index (PI), as shown in Table (4), although the soils retained some plasticity. The results have shown that the consistency limits are improved. The ash-marl mixture has changed to non plastic at 20% ash content. The soil classification is changed from A-7-6 to A-4 as per AASHTO and has changed from (CL) to (ML) at 15% ash content and to (CL) at 20% ash content. The soil has changed from medium- high plastic soil into non plastic soil.

Compaction of Ash-Marl: The maximum dry density curves for marl with different ash content are illustrated in Table (5) according to ASTM [18, 19].

Dry density of Karak ash can be considered as a low density material compared with many types of soil as clay, marl, sand and other detrital materials, this can be considered as an advantage to use ash as compacted backfill material behind retaining walls, slope stabilization, backfill on buried box culverts and similar structures. Karak ash reduces the sensitivity of soil toward water. This is clear that as the ash percent increases the optimum moisture content increases. The ash-soil sample has shown a stable behavior over a very wide range of moisture content which is ranges from 13 % to 19%. The tested ash has shown a spongy like feature and pumping when moisture content is more than the optimum (wet of optimum). Excessive water is noticed to seep out the bottom of the compaction mold during compaction due to semi squeezing process. This phenomenon is referred to the high air void content of the ash which is replaced by water before compaction and squeezing out under compaction energy. The higher void content of ash tends to limit the build up of pore water pressure during compaction, thus allowing the ash to be compacted over a larger range of water content [20].

Table 4: Summary of consistency limits for ash-marl mixtures

Ash content %	0	10	15	20
Liquid limit	44.0	38	34.0	NP (Non-Plastic)
Plastic limit	21.0	25	31.0	
Shrinkage limit	14.0	12	12.0	
Plasticity index	23.0	15	3.0	
pH	8.1	10	10.8	12

Table 5: Maximum dry unit weight and optimum moisture content for different percent of ash-clayey marl

Ash content %	0	10	15	20	30
Max. Dry Unit Weight kN/m^3	19.2	18.8	18.2	18	17.4
Optimum Moisture Content %	13.0	15.5	16.8	17	19.0

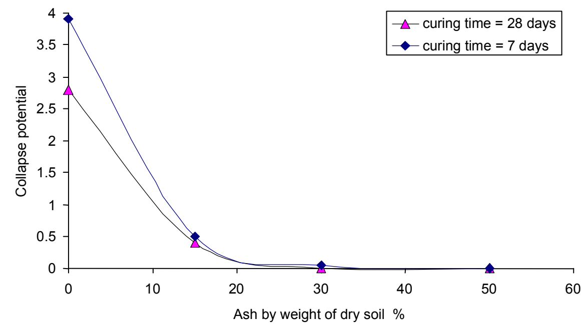

Fig. 3: Collapse potential of ash- clayey marl mixtures

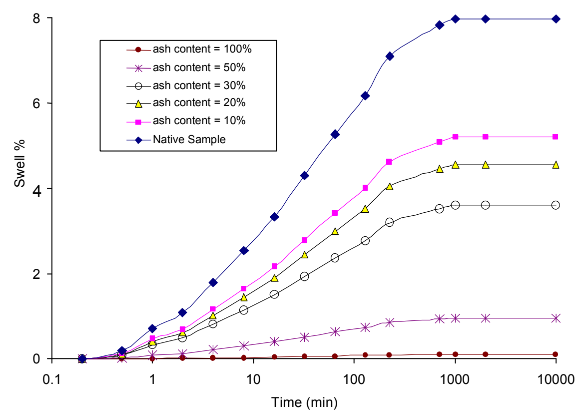

Fig. 4: Effect of ash on swelling behavior

Swelling and Collapse Potential: The collapse potential results are given in Figure (3). The collapse potential has decreased to .01 mm for the tested clayey marl sample with 15% of ash content. The collapse potential has decreased to zero when the ash content is adjusted to 30%. This is related to the increased cementaceous matrix that increased the soil stability against the internal swelling forces which is acting on the opposite direction of the internal bonding forces. It is clear that increasing the ash content beyond 30% has no effect on the consolidation behavior but has significant effect on the other strength parameters.

Swell potential was evaluated in accordance with the Kansas Department of Transportation (KDOT) method for volume change, which is a one-dimensional swell test on a 102 mm diameter, 51 mm thick sample with a 7.18 kPa surcharge. Figure (4) shows the swell for each soil at optimum moisture for that native soil. As Figure (4) shows, ash significantly reduced the swelling potential for the soil. Note that swell potential will tend to be greater for soils compacted at a moisture content that is below optimum, which is often the case for ash stabilized soils. Note also that in both figures the native soil had the highest plasticity index (PI) and the greatest swell. Although both the PI and the swell potential were reduced for this soil, the amount of swelling was still significant after the addition of ash. These results were consistent with those previously reported by many researcher [4], which they found that although the use of ash reduced swelling, CH-clays could still swell significantly after the introduction of fly ash.

Unconfined Compressive Strength: The unconfined compressive strength results are obtained for ash-marl samples according to ASTM D2166-66 standard. The samples is prepared as disturbed samples at the maximum dry density and optimum moisture content. The results revealed that the unconfined compressive strength of the clayey marl is increasing with increasing the ash content and the curing period as shown in Figure (5). The strength buildup is related to the ash alkalis-soil pozzolanic part to form a cementaceous material that possesses higher strength parameters than the original soil sample. The time factor plays an important rule for the ash alkalis-soil silica reaction to continue under normal ambient temperature. Figure (5) shows that the unconfined compressive strength of ash-marl mixtures is slightly increases with increasing ash content at 7 days in comparison with 28 days compressive strength results of the same samples.

The alkali content which is presented by CaO, the pozzolanic content which is presented by (SiO_2 +Al_2O_3+ Fe_2O_3) and the variable content of SO_3 are found in both the ash samples and OPC raw material. The strength buildup in the ash samples is related to the setting reactions of lime (CaO) with the pozzolanic constituents to produce calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH). High pH solution is highly reactive with amorphous Al-Si rich phases at normal room temperature. Sulfate minerals as ettringite are expected to form because of the availability of SO_3 in the Karak bituminous limestone and its combusted products ash sample.

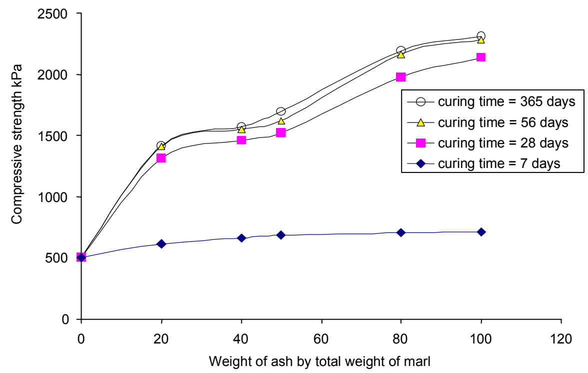

Fig. 5: Unconfined compressive strength of clayey marl-ash mixtures

The hydration products of the ash as identified by the XRD technique are portlandite, ettringite, calcium silicate hydrate and calcium aluminum hydrate. The reactions are not spontaneous and are time dependent. Curing period of 28 days and more has influenced the compressive strength results. High compressive strength values are obtained with intact samples indicating no disintegration features under fully saturated conditions. All hydrated samples have shown a similar behavior to the hydrated OPC products but with lower compressive strength.

California Bearing Ratio: The results of California Bearing Ratio *(CBR)* are obtained for ash-marl samples according to ASTM standard [21]. The CBR test results of clayey marl-ash mixtures are shown in Table (6). The results that are obtained at 28 days under soaking conditions for 96 hours directly before testing showed that CBR is increasing with increasing the ash content and curing period. CBR specimens are cured for 28 days at normal ambient temperature in summer and then soaked under water for 96 hours. Clayey marl has shown that the ash has improved the strength of the stabilized soil.

The CBR values for mixtures of the stabilized clayey marl-with ash has shown that the CBR has increased from 4% for the unstabilized parent soil samples to more than 120%. Lime (CaO), plays an important role in the strength buildup.

General Discussion: Durability of soil stabilization agents varies with the type of stabilization agent, soil type, environmental conditions and percentage of stabilization agent added to the soil in laboratory testing. To evaluate long-term performance, CBR values for the fly ash treated subgrades were compared with the age of the sample. The maximum age of the sample is one year. The result in the

Table 6: CBR values of clayey marl-ash mixtures

Wt % by total weight of dry soil	Age Days	CBR %
0		5
10	28	18
20	28	52
50	28	78
100	28	115
100	56	118
100	365	120

above tables show, again, that the fly ash treated sample were much more resistant to penetration and that no correlation was observed between CBR and age for the subgrades tested. Figure 2 shows the adverse effect of variation of water on shear strength. On the other hand, when the marl clay stabilized with ash over 50 %, the sample becomes like solid block.

In the ash samples, the excess lime is present and the formation of tri-calcium aluminate C_3S is favored. In Portland cement, the addition of gypsum could lead to the formation of ettringite $Ca_6\ Al_2O_6(SO_4)_3$.31-32 H_2O. As the mixture ages, the fibrous crystalline network continues its growth and the crystals become coarser and form interlocking network. The critical aspects in setting include the formation of CSH and CASH phases to provide the observed strength of the ash mixtures. Portlandite $Ca\ (OH)_2$ plays an important role in the setting reaction. Portlandite reacts with silicates and aluminum rich phases to form insoluble compounds which contribute to the strength formation (pozzolanic reactions). Excess portlandite reacts with atmospheric CO_2 to precipitate calcium carbonate that helps in strengthening the product after aging.

CONCLUSION

The purpose of using Karak ash is to improve the texture, increase the strength and reduce the swell characteristics of the various soils. When the additives containing free calcium hydroxide are mixed with the soil, the calcium causes the clay particles to flocculate into a more sand-like structure reducing the plasticity of the soil. This reduction in plasticity, which is called modification, reduces the shrink/swell characteristics of the soil. Soil stabilization includes the effects from modification with a significant additional strength gain. The soil must be able to react with the chemical additives to achieve the soil stabilization or modification that is desired. Another few point could be concluded as follows:

- Subgrade or embankments of marl clay as poor soils can be stabilized efficiently by using ash by increasing the strength and CBR, also by reducing the swelling and collapse potential.
- The soil plasticity decreases as the ash content increases.
- To stabilize the ash-marl soil mixtures could be prepared with equivalent weights (ash/soil =1:1 and 1:2). The mixtures are compacted to maximum dry density and optimum moisture content.
- The efficiency of stabilization has increased with the increase ash content and curing time.
- The silica content is higher in the stabilized soil samples.
- The sensitivity of soil toward water totally disappear.
- There is no deterioration or disintegration of the sample that stabilized with Karak ash over time. This was confirmed by testing of the samples after one year.

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