

EFFECT OF USING POZZOLANIC MATERIALS ON THE PROPERTIES OF EGYPTIAN SOILS

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Abstract: The possibility to use a large amount of waste materials as a replacement for the imported virgin material in road construction has been recognized. RoadCem is a soil stabiliser provides cheap and more environmentally friendly source of materials for road construction to use with in-situ material. This results in reduction in the required thickness of the pavement consequently reducing costs and contributes to the solution of declining resource of imported materials. An extensive study was carried out on a sample of Egyptian soil. RoadCem as a primary stabiliser with ground granulated blast furnace slag (GGBS), lime and ordinary Portland cement (OPC) were employed. The results revealed that the unconfined compressive strength (UCS) and the modulus of elasticity (E_{40}) of the test soil increased while the free swelling percent (FSP) decreased with an increase in the total stabiliser and the curing period.

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1. Introduction and Problem Definition

The traditional section for road typically consists of different layers such as the surface coarse, base and sub-base courses. These layers are typically made of imported materials that require transport, environmental and other costs increase with the distance to the source of the materials. The reliance on imported material is the main problem, from a sustainability and efficiency point of view, of the traditional road and pavement design and construction. Due to the gradual depletion in the conventional resources, searching for a more rational road construction approach aimed at reducing the dependence on imported materials while improving the quality and durability of the roads is necessary [5].

Many chemical substances have been used to stabilise soils, e. g. lime, OPC, and GGBS. Lime and OPC are the two common additives which have been employed in stabilisation of Egyptian subgrade to produce a base or sub base layer instead of importing granular base course materials [7]. Modern societies produce large quantities of waste materials often disposed off in landfill and considered not to have any value. As the society develops, larger quantities of waste materials continue to be generated by people and these mountains of waste are also becoming a problem. The possibility to use a large amount of these waste materials as a replacement for the imported virgin material in road construction has been recognized as an option. Up to now only a limited portion of the waste stream could be brought to use in road construction due to pollution problems associated with reuse of waste materials in road construction [5].

RoadCem is a blend of special selected substances in various percentages with each individual, chemical specific characteristics. It is an additive and OPC improver, used in soil stabilisation typically for road construction [5]. The use of RoadCem can control of waste streams and pollution, on the other hand it can provide cheaper and more environmentally friendly source of materials for road construction. This results in the reduction of the required thickness of the pavement structures consequently reducing road costs and contributes to the solution of the problem of declining resource base for imported materials [5].

Although RoadCem may be expensive materials, using it in very small percentages together with OPC and/or other pozzolanic materials to produce major improvement in the soil properties may be economic. The main challenge is to secure sufficient funding both to maintain the existing network and to accommodate the extensions to the network that are deemed to be necessary for rural development and for the attainment of poverty reduction goals.

An extensive laboratory study was carried out on a sample of a test soil chosen from Ain Shams district, east Cairo, Egypt. Many additives were employed in this investigation such as RoadCem, OPC, GGBS and lime with different percentages according to the test programme listed below.

2. Materials and Methods

2. Materials

2.1. Test Soil

The main objective of this research was to evaluate the use of RoadCem, OPC, lime and GGBS, as stabilizers on a sample of natural soil. The particle

Table 3. Chemical composition of hydrated lime, RoadCem and GGBS

Composition	Lime [7]	RoadCem	GGBS [7]
SiO ₂	0.46 %	21.4%	34.8 %
Al ₂ O ₃	0.10	1.99	10.7
Fe ₂ O ₃	0.06	0.62	1.2
TiO ₃	0	0	0.6
Ca O	0	47.3	36.4
Mg O	0.83	4.1	1.9
Mn O	0	0	5.4
Ca (OH) ₂	96.79	0	0
Ca CO ₃	1.36	0	0
Ca SO ₄	0.06	0	0
Fe O	0	0	0.75
Fe	0.60	0	0
S	0	0	0.85
Ba O	0	0	6.0
K ₂ O	0	7.44	0
H ₂ O	0.34	16.45	0

3. TEST PROGRAM

Two different mixes in addition to a control mix and two different stabiliser contents for each mix were used in this investigation. The test program and composition of mixes are illustrated in tables 4 and 5 [4].

Table 4. Test programme

Mix 1	Mix 2
2% RoadCem	2% RoadCem
98% OPC	33% OPC
	50% GGBS
	15% Ca (OH) ₂

Table 5. Composition of mixes

ixes	Stabiliser %	Weight of components in grams				
		Natural soil	RoadCem	OPC	Lime	GGBS
1	6%	22500	27	1323	-	-
	12%	22500	54	2646	-	-
2	6%	22500	27	445	203	675
	12%	22500	54	890	406	1350

4. Experimental Study

4.1. Compaction Test

The compaction test was carried out for the determination of the optimum moisture content (OMC) and the maximum dry density (MDD). This test covers the determination of the mass of dry soil per cubic metre when the soil is compacted over a selected range of moisture contents, covering that giving the maximum. The first phase of this study involved a detailed investigation of the compaction characteristics of the test soil containing different percentages of stabiliser, in order to obtain the OMC and MDD. The moisture contents used in preparing specimens for all tests were OMC + 2% as the author believes that this moisture content gives better

conditions for the chemical reactions and the strength development to take place. This moisture content was kept constant for all mixes, to maintain consistency of the results.

4.2. Specimens Preparation

4.2.1. Mixing

Mixing of dry materials was performed using a Hobart variable speed mixer. A quantity of distilled water equal to the (OMC + 2%) as obtained from the standard compaction tests was used. The OMC varied from 9.54% for test soil to 11.28% for test soil + 12% of mix 2, as a percentage of dry weight of soil. Dry materials, enough to produce twelve compacted cylindrical test specimens 50 mm in diameter and 100 mm in length, were thoroughly mixed in a variable speed Hobart 1/4 hp mixer at the lowest speed for 3 minutes before slowly adding the calculated amount of water. The mixing paddle, the bottom and the inside of the mixing bowl were scraped free of the materials and then additional hand mixing with palette knives was carried out to ensure a uniform dispersion and to produce a homogenous mixture.

4.2.2. Compaction

A predetermined amount of materials, sufficient to produce one sample, was placed in a mould specially designed for this purpose. Prior to filling, the inside of the moulds were lightly covered with mould oil to facilitate extrusion after compaction. The amount of material placed in the mould was that required to achieve the previously determined MDD (from 2.0 T/m³ to 2.13 Mg/m³) for a height of 100 mm. The specimen was weighed, measured, and placed in sealed double polyethylene bags to ensure minimum loss of moisture during the curing period. The specimens were then labeled and stored under required curing condition.

4.2.3. Curing

Specimens were placed in the curing room which was maintained at (30 ± 2°C and 50% relative humidity). The curing periods varied from 3 days to 28 days. The curing conditions were selected to represent those that might be achieved in Egypt in most days of the year. The moisture content for all mixes after all curing periods was registered.

4.2.4. Unconfined compressive strength test procedure (UCS)

The second phase of this study involved a detailed investigation of the strength tests (UCS) and the volume stability test (FSP). To carry out these tests the specimens were taken out from the storage bags at the end of the curing periods, weighed to the nearest 0.01g and the dimensions were measured. All specimens were tested in a universal test machine with a loading rate of 1.2 mm/min, so that the specimen fails in about 5 minutes, until failure. A minimum of three specimens of each mixture were

tested. The results presented below are the average values.

4.2.5. Free swelling test procedures

After finishing the strength tests, about 50 g of materials was oven dried at 50° C, ground and passed through a 425 μ sieve. The soil powder was then placed loosely in a dry 25 ml cylinder up to the 10ml mark without any compaction. 50 ml of distilled water was placed in a 50 mm diameter measuring cylinder. The dry soil powder is then poured slowly into the water. The water and soil were then left for at least half an hour. The volume of settled solids was then measured (V_{ml}). Free swell was then calculated from the equation below [1].

$$FreeSwell = \frac{V - 10}{10} \times 100$$

5. Results

5.1. Unconfined Compressive Strength Of Mixes

The effects of adding stabilisers of different mixes on the UCS of the test soil for 6% and 12% total stabiliser are presented in figure 2. It can be observed that generally the UCS of the test soil increased with an increase in the curing period for the same combination. For example, the UCS of the test soil increased from 795 kN/m² to 2640 kN/m² with an increase in the curing period from 3 to 28 days of mix 1, at 6% stabiliser content. Replacement of 65% OPC by GGBS and lime (mix 2) increased the UCS to 2460 kN/m² and 2820 kN/m² after 28 days at 6% and 12% stabiliser respectively.

5.2. Free Swelling Testing Of Mixes

The initial (FSP) of the test soil was 30%. The effects of adding stabilisers of different mixes on the (FSP) of the test soil are presented in figure 3 for 6% and 12% stabiliser respectively. It can be seen that generally the FSP of the test soil decreased with an increase in the total stabiliser and with an increase in the curing period for the same combination at total stabiliser of 6%. Increasing the total stabiliser to 12% caused a further decrease in the FSP for the same combination. For example, the FSP of the test soil decreased from 30% to 7% with an increase in the curing period from 3 to 28 days for mix 1 at 6%, while the FSP decreased from 30% to 5% with an increase in the stabiliser content to 12%, keeping all other conditions constant. Replacement of 65% OPC of the total stabiliser by GGBS and hydrated lime (mix 2) reduced the FSP of the mix to 10% only at 6% total stabiliser after 28 days. However, no further decrease was observed in the FSP values at 12% total stabiliser.

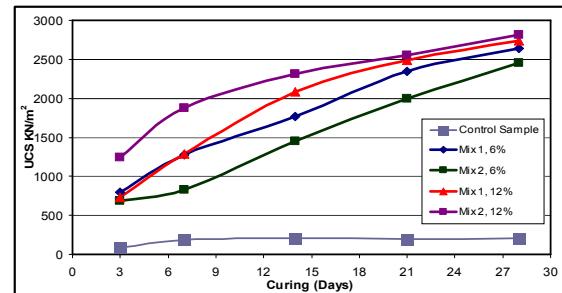


Figure 2. Effect of using stabilisers on UCS of the test soil

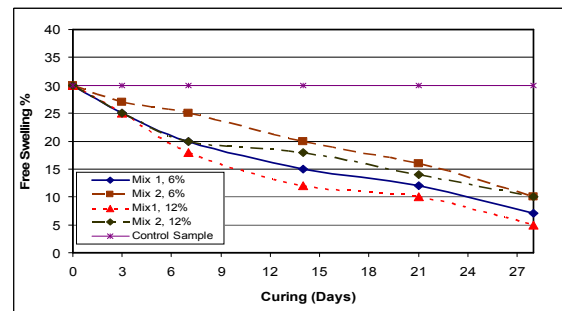


Figure 3. Effect of using stabilisers on the free swelling%

5.3. Modulus Of Elasticity Of Mixes

The effect of stabiliser on the stress / strain (σ/ϵ) behaviour as described by (E_{40}) of the test soil is given in figure 4. (E_{40}) is defined as the ratio of 40% of the maximum UCS to the corresponding strain. It was used in this investigation to study the effect of adding RoadCem, OPC, GGBS and lime on the elasticity behaviour of the test soil instead of using the initial modulus of elasticity to get more representative values as the initial modulus could be affected by the surface conditions of the specimens.

It can be seen that the modulus of elasticity (E_{40}) generally increased with an increase in the stabiliser content and with an increase in curing period, with only few exceptions. Also, (E_{40}), after 7 days, reached to (50% to 60%) of its maximum value after 28 days for the same mix. For example, (E_{40}) of the mix 2 with 12% stabiliser increased from 3680 kN/m² to 21550 kN/m² after 7 days and then further increased to 35255 kN/m² after 28 days. Replacement of 65% OPC with GGBS and lime caused a decrease in the (E_{40}) by about 20% at 6% stabiliser, while the (E_{40}) increased by 20% at 12% stabiliser for the same mix. The increase in (E_{40}) with an increase in the stabiliser content and curing period is probably due to the changes in the composition and the formation of the cementitious materials which have direct effects on the deformation properties of the test soil.

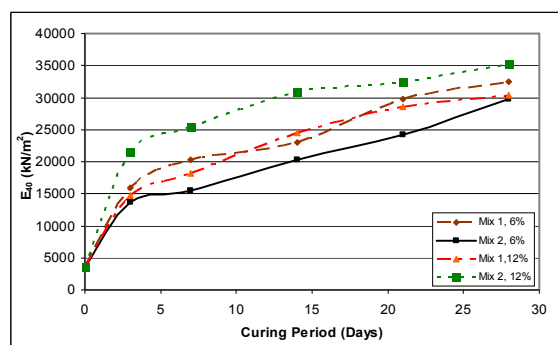


Figure 4. Effect of using stabilisers on the E_{40}

6. Discussion

The increase in strength represented by the UCS with an increase in the total stabiliser content probably results from the reaction of the stabiliser with the clay portion of the test soil and the formation of new cementitious materials. There is also a possible effect on the moisture content of the soil due to the water demand of the lime and/or changes of moisture content due to drying/wetting of the sample. Changes of water content could change the pore suction of the sample which could have a small effect on the strength [7]. The rate of the formation of cementitious materials, is the main reason for the strength increase with an increase in the curing period due to development in the crystallinity and percentage of the cementitious materials. The increase in elasticity expressed in (E_{40}) is associated with the increase in the strength which is primarily due to the formation of new cementitious materials.

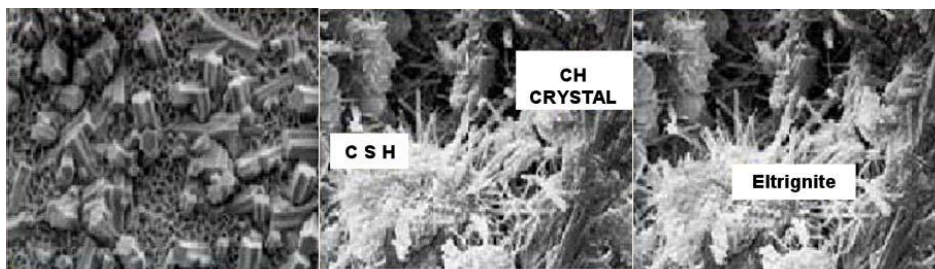
A previous work on similar mixes proved that the CBR values increased dramatically with the increase in the total stabiliser [8]. The great increase in the UCS means a greater increase in the CBR value of the mixes. In road design, it is well known that the thickness of asphalt layers inversely proportional to the CBR values. It may be economic to use soil stabilisation technique using these mixes to increase the CBR values of the subgrade soil and thus reduces the asphalt layer thickness and the base layer may not be used. Optimization study carried out by Ouf and El-Hakem, show that it is possible to reach a UCS of 1792 kN/m² with a 5% swelling by considering an 11% Lime/GGBS and a 7% stabiliser at 37°C curing temperature for 27 days. It can be observed from this investigation that approximately the same gains in strength and the same reduction in free swelling percentage can be obtained easily using 6% of stabiliser or low after 14 days [9].

Previous research [7, 12] on clay-lime system and pozzolanic reactions has showed that the type, form, amount and characteristics of the reaction products control the physical, chemical and

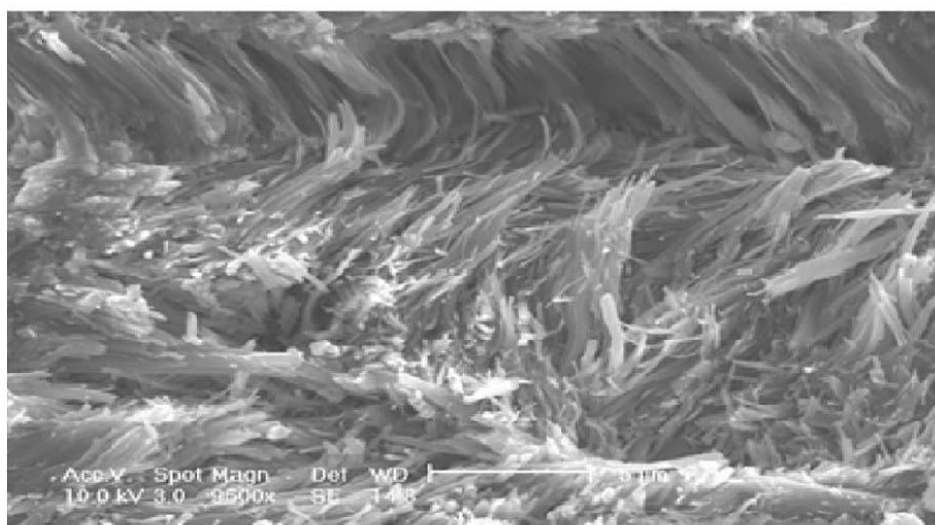
mechanical properties of the bulk material after stabilisation. Thus, the nature of the long-term cementation in clay stabilisation will, depending on the effect of the curing conditions and time. The primary cementing agent in all clay lime stabilisation systems is aluminium substitute calcium silicate hydrate (C-A-S-H) gel. The pore solution of these systems contains silicate and aluminate ions which are formed by the dissolution of clay particles in the highly alkaline environment provided by the dissolved lime [7]. In clay-GGBS-lime systems, the primary cementing agent is still C-A-S-H gel. Due to the high alumina content of GGBS, some alumina is expected to replace silica and C-A-S-H gel is probably also formed.

In clay-GGBS-lime-OPC systems (mix 2), two reactions were expected, hydration of GGBS activated by lime to produce C-A-S-H gel and hydrotalcite type phase containing magnesium, and clay-lime reactions producing C-A-S-H and calcium aluminate hydrates. The major reaction in the short-term is the hydration of GGBS activated by lime which normally starts immediately after mixing the dry materials with the required mixing water. GGBS hydration usually consumes a relatively large amount of water and a relatively small amount of lime [7]. Some free lime however, is still present after GGBS hydration in the mixes depending upon the percentage of lime added, as the required amount of lime to activate GGBS is very small [7]. As a result of GGBS hydration, the mixing water available for lubrication dramatically decreases and the air void content increases, and more water is needed to obtain the same level of lubrication at the same compaction effort. Therefore, the OMC increases with increasing total stabiliser.

OPC needs moisture for hydration and becomes an effective binder of other appropriate materials such as aggregate, sand etc. The reaction of water with the OPC is extremely important to its properties as a binder. When water is added to OPC, each of the compounds contributes to the final product. Tricalcium silicate and dicalcium silicate are responsible for the early and later strength respectively. Upon the addition of water, tricalcium silicate rapidly reacts to release calcium ions, hydroxide ions, and a large amount of heat. The reaction slowly continues producing calcium and hydroxide ions until the system becomes saturated. Once this occurs, the calcium hydroxide starts to crystallize. Simultaneously, calcium silicate hydrate (C-S-H) begins to form. The formation of the calcium hydroxide and (C-S-H) crystals provide "seeds" upon which more C-S-H can form.



A. End Product of Cement Hydration Showing Elements of Crystalline Structure Formed



B. End Product of Cement + RoadCem Hydration Showing Extended and More Pronounced Crystalline Structure Formation and “Wrapping” Effect

Figure 5. Electron micrographs for the typical structures of end products [5]

The C-S-H crystals grow thicker which makes it more difficult for water molecules to reach the anhydrate tricalcium silicate. The speed of the reaction is now controlled by the rate at which water molecules diffuse through the C-S-H coating. This coating thickens over time causing the production of C-S-H to become slower [5].

When RoadCem is used as an additive, moisture remains necessary for hydration and hardening. The five major compounds of the hydration process of OPC still remain the most important hydration products but the minor products of hydration probably change. Furthermore, the rate at which important hydration reactions occur and the relative distribution of hydration products changes as a result of the addition of RoadCem. In addition the crystallization of calcium hydroxide accordingly occurs at different rates and the reduction of heat generation from the hydration reactions occurs. There are more crystals formed, when RoadCem is added, during the reactions and the relevant crystalline matrix is much more extensive. Also when RoadCem

is mixed with OPC, it forms interlocking needles throughout the mixture, creating a strong 3D mineral structure. Also, the amount of water trapped as free water is reduced and the crystals grow into the empty void space. This makes the product less permeable to water and more resistant to all types of attack that are either water dependent or water influenced. Figure 7.A and 7.B show electron micrographs for the typical structures of end products with cement alone and with cement and RoadCem added respectively. It can be seen with these two photographs that the addition of RoadCem creates a different structure. Also, electrochemistry change is induced by the addition of RoadCem. It makes it possible to bind different materials even in acidic environments and when combined with the “wrapping effect” leads to a product which has superior characteristics and performance [5].

The durability, including physical and long-term leaching performance of the final product is a key consideration that should be determined. The approach selected to address durability questions will

depend on the design life, properties of the treated material and potential risk to receptors (e.g. groundwater). Durability can be assessed by considering the failure mechanisms that may affect the bonds between treated materials.

A simple definition of leaching is the transfer of a substance or compound from a solid to a liquid phase when the two are in contact. It is a complex phenomenon and occurs in nature as a result of physical and chemical weathering processes involving the interaction between a soil or rock and water. The amount, or rate, of leaching of a particular substance from a solid matrix, can be influenced by a large number of physical, chemical and biological factors [10].

Leaching behaviour is dictated predominantly by the mechanism of release (percolation or diffusion) [10]. A significant work has been carried out to harmonise leach tests for a wide variety of materials and comparison of numerous test methods has led to the development of standard tests to permit the characterisation of leaching performance for a range of disposal and re-use scenarios.

7. Conclusion

1. The UCS of the test soil generally increased with an increase in the total stabiliser and with an increase in the curing period for the same combination. Replacement of 65% OPC by GGBS and lime caused a further increase in the UCS at 12% stabiliser, while the UCS decreased at 6% stabiliser.
2. Generally the FSP of the test soil decreased with an increase in the total stabiliser and with an increase in the curing period for the same combination at total stabiliser of 6%. Increasing the total stabiliser to 12% caused a further decrease in the FSP for the same combination.
3. The (E_{40}) of the test soil increased with an increase in the total stabiliser and with an increase in the curing period for the same combination. Also, (E_{40}), after 7 days, reached to (50% to 60%) of the maximum value after 28 days for the same mix.
4. High temperature can accelerate hydration of stabilisers in road materials, resulting in raveling of the aggregate and brittle fracture of the layer. When RoadCem is used this mode of failure is largely eliminated.

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