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Studying the Effect of Adding GGBS and Lime on the Engineering Properties of Subgrade Clay Soil

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ABSTRACT

The effects of ground granulated blast furnace slag (GGBS) with and without lime on the engineering properties of the test subgrade soil are presented. Samples were separated into two batches; one was placed in the curing room which was maintained at curing condition (20°C and 90-100% relative humidity) (CC_l) and (35°C and 50-60% relative humidity) (CC_2). The results showed that the addition of GGBS activated by lime has a small effect in compaction properties, a decrease in the maximum dry density and an increase in the optimum moisture content, Adding GGBS activated by lime dramatically increased the unconfined compressive strength (UCS) of the test soil. The UCS of the test soil increased with an increase in binder content, the lime/GGBS ratio, the curing period and the temperature. Also, the addition of GGBS activated by lime decreased the free swelling percentage (FS %) of the test soil. The (FS %) decreased with an increase in the binder content, lime/GGBS ratio, curing period and curing temperature.

Keywords: *GGBS; Lime; UCS; swelling.*

1. Introduction

Economic development of the countries is controlled to some extent by the highway networks. In order to decrease the cost of pavement construction, it is necessary to take into consideration the properties of the subgrade soil before design the type and the thickness of the pavement, as the subgrade carries the traffic loads and the pavement loads (Bari, 1995).

Imran et al. (2016) observed that expansive soil lead to failure due to the high level of ground moisture. Innovative methods of soil stabilization like mechanical and chemical stabilization are in high demand all over the world. Although mechanical stabilization, by increasing the compactive effort and dry density of the soil mix, also, durability and strength increases. Like lime, GGBS, fly ash, cement, and other additive materials using for soil stabilization is more advantageous.

Yadu and Tripathi (2013) observed that replacing of weak soil with good quality soil is another way to obtain a strong foundation, but there are economic and environmental concerns. Transportation of large amount of soil and disposal of industrial waste hurts projects economy and environment. Common strategies want to improve properties of soil including compressions, poor water reduction techniques, and bonding of soil particles by the freezing method, geotextile, and stone column.

Yi, Li, Liu, and Asce (2015) stated that, generally, lime is used for the following reasons; firstly, decrease the liquid limit (LL) and an increase in plastic limit (PL) that leads to a substantial decrease in the plasticity index (PI) and excellent workability. Secondly, the chemical reaction that occurs between soil and lime leads to a decrease in the water content.

Sharmila (2016) noticed that, the utilizing of local fly ash and GGBS in road construction is the way to reduce the amount of waste causing environmental pollution. Various tests for evaluating the stabilized soil like specific gravity, Atterberg limits, CBR and standard Proctor carried out on the soil. Based on CBR determination, the optimal amount of GGBS and fly ash was 20% and 15% respectively. The results revealed an increase in maximum dry density (MDD) and compatibility of soil, while the moisture content decreased by the increase of fly ash and GGBS%. Lastly, the result showed that the optimum value for GGBS is 20% and for fly ash is 15%.

Dayalan and Dayalan (2016) observed that, after mixing the stabilizer content (fly ash, GGBS) different tests like PL, PI, LL, OMC, MDD, UCS and

CBR both soaked and un- soaked should be conducted in the modified soil. The various percentages of fly ash up to 10% and a fixed amount of 10% GGBS was added to soil sample and the result showed an increase in MDD from 1.73 gr/cm3 to 177 gr/cm3 and a decrease in OMC from 16.5% to 15.8% further mixing of fly ash was led to vice versa results. Also, the recommended value of fly ash and GGBS that should be used in soil denoted a value of about 10%.

GGBS is a latent hydraulic material that would hydrate very slowly on its own (Shi et al., 2006). GGBS on its own has only mild cementitious properties and it is generally used in combination with Portland cement or hydrated lime (calcium hydroxide) which provides the necessary alkali for activation (Richardson and Groves, 1992).

2. Reviewing of the Literature

The significance of the current work arises from the fact that SCC basic requirement is related to its Soil stabilization is used to improve the mechanical properties of inferior soils in the construction of civil engineering projects such as road pavements, sub-grades, subbases, runways and shallow foundations. Ouf (2001) reported that the activator creates an appropriate environment for the hydration process of GGBS without necessarily playing a significant role in the reaction.

Soil stabilization using lime occurs in soils containing a suitable percentage of clay and the proper mineralogy to produce long-term strength; and permanent reduction in shrinking, swelling, and soil plasticity (National Lime Association, 2012).

The potential use of GGBS in road construction was studied initially by evaluating their physical and chemical characteristics. The by-product materials were mixed with local soils and their geotechnical characteristics were investigated. The feasibility of using these mixes in the base course of road pavement was investigated by adopting stabilization techniques. It was concluded that, a mixture of slag, fly ash, and soil has potential for use in sub-base, base, and wearing courses of road pavement (Osinubi, 2010).

Rogers et al., (1997) studied the effect of lime modification on four different clay soils. They demonstrated that the liquid limit generally increases with low lime content. However, the plastic limit requires a greater lime addition to attain a significant change. Mathur, et al. (2007) carried out a study on a sample of clay treated with lime and GGBS. The results of tests showed that properties of the soil improved when treated with lime – GGBS blends. (FS %) and linear shrinkage decreased, while the UCS and CBR values increased. Optimum properties of the clay– lime- GGBS mixture were obtained at 8% lime and 7.5% GGBS based on strength assessments. Accordingly, the mixture can be used as sub-base and base courses for light traffic roads.

Water is strongly adsorbed at the negatively charged particle surfaces. Thus, an extensive adsorbed layer is formed due to the concentration gradient between the bulk solution and the electrical double layer (consisting of water molecules and exchangeable cations).

Abdi and Wild (1993) studied the effect of lime percentage on the compaction characteristics of kaolinite clay. The MDD decreased with an increase in the lime content, while the OMC increased with an increase in the lime content. Mohamed et al., (1991) studied the effect of adding lime and cement on the compaction properties of three types of natural Egyptian soils (sand, sandy clay and clay). They found that, both lime and cement caused a reduction in the MDD and an increase in the OMC in all types of soils.

Anand et al., (1996) tested Louisiana silty clay soil as a sub-grade for UCS and the (CBR) at five different moisture contents and dry density levels. They found that lime treatment increased the UCS, which was found to be directly proportional to the curing period.

3. Methodology and Testing Procedures

The methodology and testing procedures of this research comprising compaction tests (as obtaining the OMC and the MDD of the clay-GGBS-lime mixtures), UCS tests together with sample preparation (i.e. mixing, compaction and curing), and methods for assessing the swelling characteristics.

Mixing of samples was performed using a Hobart variable speed mixer. Water used was that required to obtain the OMC as obtained from the compaction tests. The OMC used in this investigation was to obtain the MDD for each individual mixture.

Samples were separated into two batches, one was placed in the curing room which was maintained at (CC_l) and the other half was cured at (CC_2). The curing times varied between 7 and 28 days.

4. Test Results and Discussion

The effect of GGBS with and without lime on the engineering properties of the test subgrade soil, compaction, plasticity characteristics, (UCS) and swelling characteristics, are presented in this study. The UCS and FS% tests were conducted on specimens that were cured under two curing conditions (CC_l and CC_2), for varying periods (i e. 7 and 28 days). The compaction tests were carried out immediately after adding the binders. The compaction, UCS and FS% tests were carried out on the test subgrade Egyptian soil. Test soil were sealed and stored until they were needed to produce the test soil. The test subgrade soil composed of 80% mainly kaolinite and 20% calcium montmorillonite.

3.1 Dry Density – Moisture Content Relationship

Modified Proctor tests were used to establish the dry density-moisture content relationship for the test subgrade soil and to provide data for the preparation of specimens for UCS tests. Modified Proctor compaction tests were carried out on the test subgrade soil with various amounts of GGBS added to investigate the effect of adding GGBS on OMC and MDD. It also carried out on the test subgrade soil with 2, 4, and 6% total binder (GGBS +lime) by dry weight of soil. GGBS replacement by lime was 10, 20 and 30% of the total binder percent (2, 4 and 6% of dry weight of soil).

The following figures show the effect of GGBS and GGBS – Lime on soil mixtures on dry density – moisture content relationship. The results showed that:

1. The addition of GGBS alone to the test soil slightly decreased the MDD from 1.78 Mg/m3 to 1.69 Mg/m3, while it increased the optimum moisture content from 19.3 % to 22 %, with an increase in the GGBS content from 0% to 10%.

2. The addition of GGBS and lime to the test soil further increased the OMC with an increase in the total binder at a constant lime/GGBS ratio. The OMC also increased with an increase in the lime/GGBS ratio at a constant total binder percentage. The addition of the GGBS and lime further decreased the MDD of the test soil.

3. The rate of increase in the OMC increased with an increase in the total binder percentage at a constant lime/GGBS ratio. Also, the rate of decrease in the MDD increased with an increase in the total binder percentage.

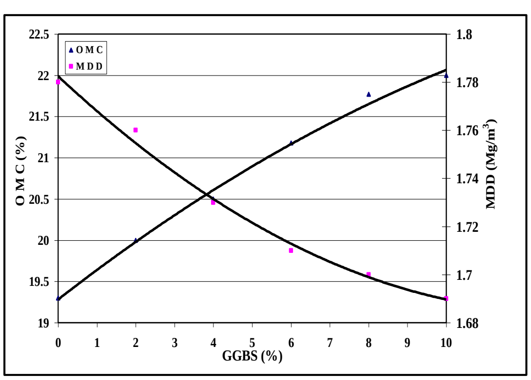

Figure 3.1 - Effect of GGBS only on the maximum dry density and optimum moisture content of the test soil

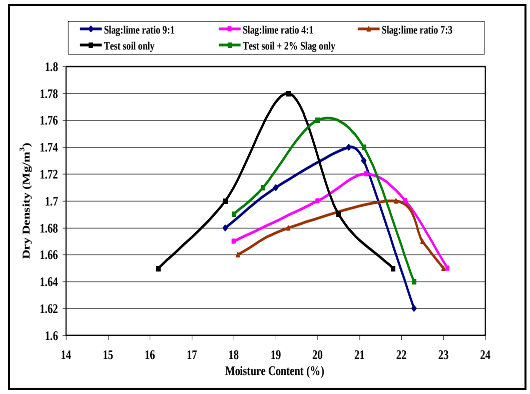

Figure 3.2 - Compaction curves for test soil only, test soil + 2% GGBS and test soil + 2% binder (GGBS+ lime)

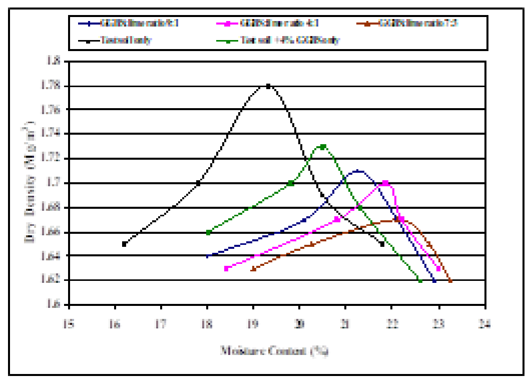

Figure 3.3 - Compaction curves for test soil only, test soil + 4% GGBS and test soil + 4% binder (GGBS+ lime)

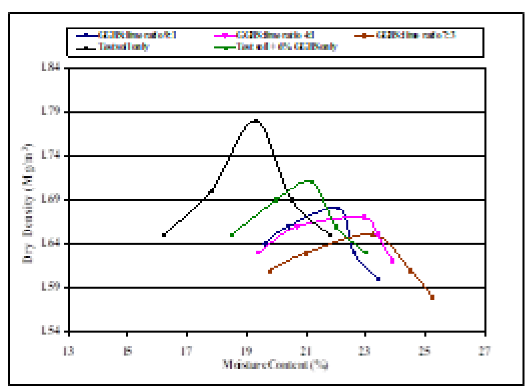

Figure 3.4 - Compaction curves for test soil only, test soil + 6% GGBS and test soil + 6% binder (GGBS+ lime).

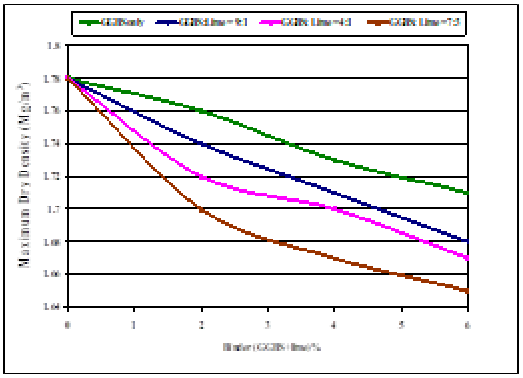

Figure 3.5 - Effect of the total binder (GGBS and lime) (%) on the maximum dry density of the test soil

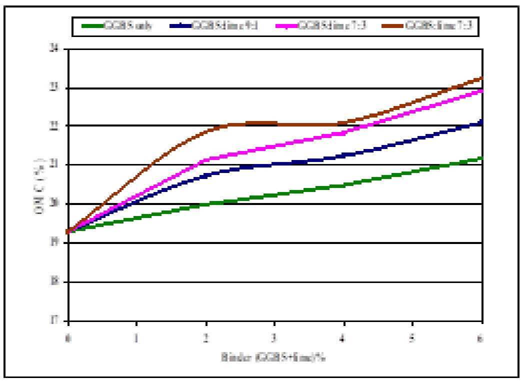

Figure 3.6 - Effect of the total binder (GGBS and lime) (%) on the maximum dry density of the test soil

3.2 UCS OF GGBS – Lime Subgrade Soil Mixtures

The UCS test was used to assess the strength development of the test subgrade soil with varying GGBS content, lime/GGBS ratio, curing conditions and curing periods. The UCS tests were carried out to study the effect of GGBS activated by lime on the UCS of the same test soil. Two curing periods were employed 7 and 28 days. The curing conditions are described CC1 and CC2. Each group of samples with the same binder content, and the same lime/GGBS ratio, were compacted at their MDD and their OMC. Cylindrical specimens with an average diameter of 38 mm diameter and a height of 76 mm were prepared and weighed.

Three total binder (T B) percentages (GGBS + lime) were used in this investigation, 2, 4 and 6%. Three different percentages of GGBS replacement by lime (10, 20 and 30%) were used with the three total binders at the same curing conditions, CC1 and CC2 were used.

The effects of GGBS activated by lime on the UCS of the test soil are presented in figures 4.7 to 4.12. It can be observed that, generally the UCS of the test subgrade soil increased with an increase in the total binder and with an increase in lime/GGBS ratio. The UCS also increased with an increase in the curing period and an increase in the curing temperature for the same binder and lime/GGBS ratio.

The increase in the UCS with increases of the lime/GGBS ratio at the same binder content is due to the GGBS needs a sufficient amount of lime to activate it. The optimum amount of lime depends primarily on the type of subgrade soil and curing conditions. Higgins et al., (1998) found that the optimum lime/GGBS ratio to achieve maximum UCS is 1: 5 (the total binder was 6% of the dry soil weight) for kaolinite clay and that the optimum is about 2/3 for Kimmeridge clay (the total binder was 5%).

It was also suggested by Wild and Tasong (1999) that a lime/GGBS ratio of 1: 5 is enough to activate GGBS. They also suggested that the lime activated GGBS hydration reaction is quicker than the pozzolanic reaction of lime with clay and the main reaction products are C-A-S-H gel and hydrotalcite.

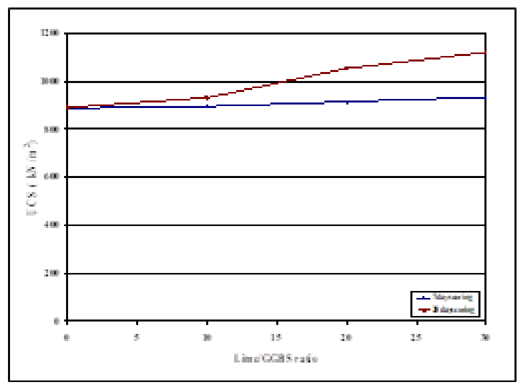

Figure 3.7 - Effect of lime/GGBS ratio on the UCS of the test soil at a total binder content of 2 % under CC_1 conditions

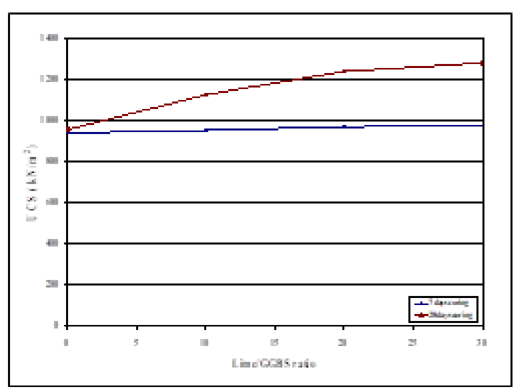

Figure 3.8 - Effect of lime/GGBS ratio on the UCS of the test soil at a total binder content of 2 % under CC_2 conditions

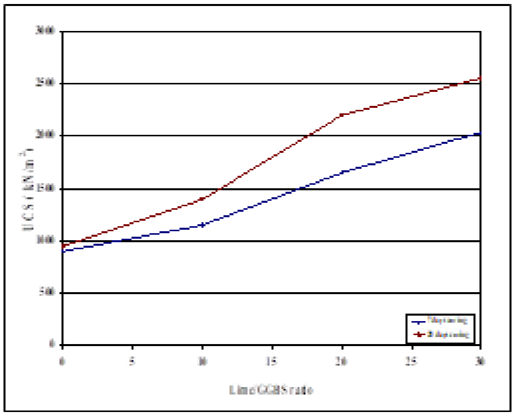

Figure 3.9 - Effect of lime/GGBS ratio on the UCS of the test soil at a total binder content of 4 % under CC_1 conditions

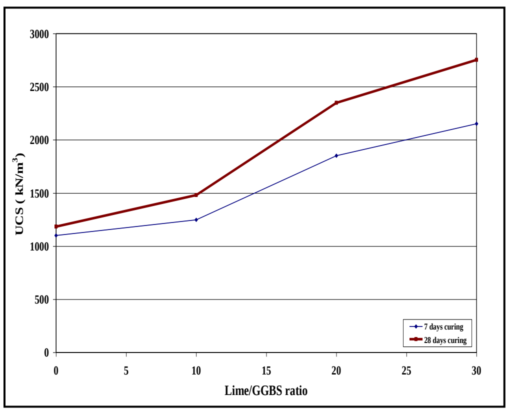

Figure 3.10 - Effect of lime/GGBS ratio on the UCS of the test soil at a total binder content of 4 % under CC_2 conditions

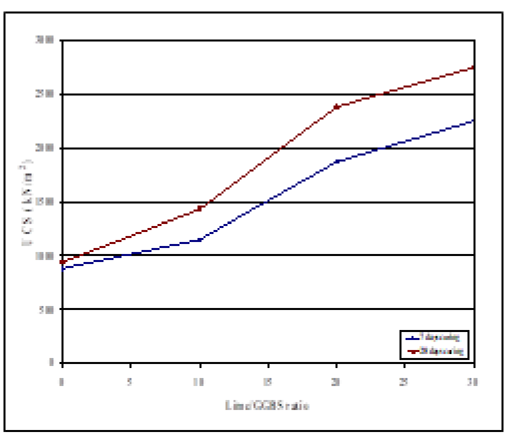

Figure 3.11- Effect of lime/GGBS ratio on the UCS of the test soil at a total binder of 6 % under CC1 conditions content

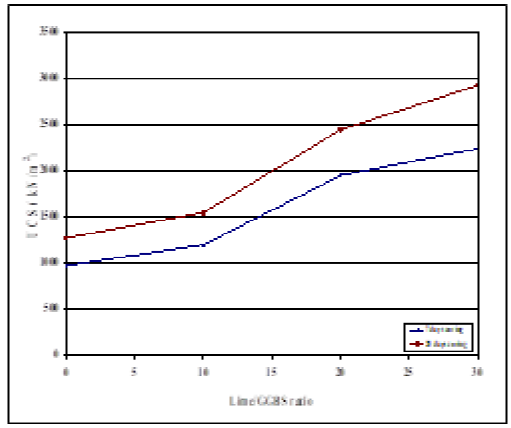

Figure 3.12 - Effect of lime/GGBS ratio on the UCS of the test soil at a total binder content of 6 % under CC_2 conditions

3.3 Characteristics OF GGBS – Subgrade Soil and GGBS – Lime - Subgrade Soil Mixtures

The effects of GGBS on the swelling characteristics of the test soil were studied in two stages. The first was the effect of GGBS alone on the swelling characteristics of the test soil, cured for different curing periods and different curing conditions. The second was to study the effect of GGBS activated by lime on the FS% of the test soil. Six curing periods were employed for the first phase, 7 and 28 days and 3,6, 9 and 12 months while two curing periods were employed for the second phase of tests, 7 and 28 days.

3.3.1Effect of GGBS Only the Free Swelling Percentage of the Test Subgrade Soil

The effects of GGBS only on the swelling characteristics of the test soil, cured under CC_1 and CC_2 conditions are illustrated in figures 4.13 and 4.14. It can be observed from these figures that the percentage of FS% decreased with increasing GGBS content. For example, the addition of 4% GGBS decreased the percentage of FS% by 5% swelling, while the addition of 10% GGBS decreased it by 15% swelling under both of the two curing conditions, after 7 days.

3.3.2Effect of Curing Periods on the Free Swelling Percentage of the Test Subgrade Soil Treated with GGBS

The effects of curing periods on the FS%, under CC_1 and CC_2 conditions, are illustrated in figures 4.15 and 4.16. It can be observed from these figures that the FS% decreased with an increase in the curing period, keeping the GGBS content constant, under the same curing conditions. For example, the FS% decreased from 30% for the control sample to 15% with an increase in GGBS to 10% after 28 days, under CC1 conditions, while the percentage of FS% also decreased the same percentage with an increase in the GGBS to 6% after 6 months.

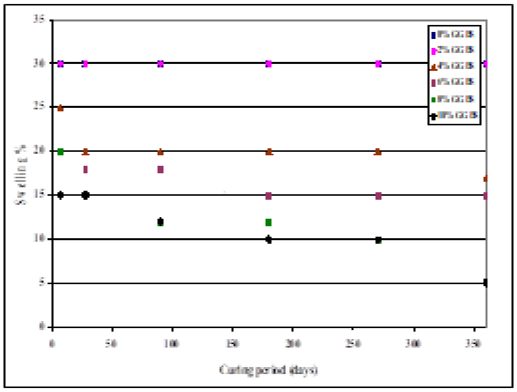

Figure 3.13 - Effect of GGBS (%) on the free swelling of the test soil, cured under CC_1 conditions, at different curing periods

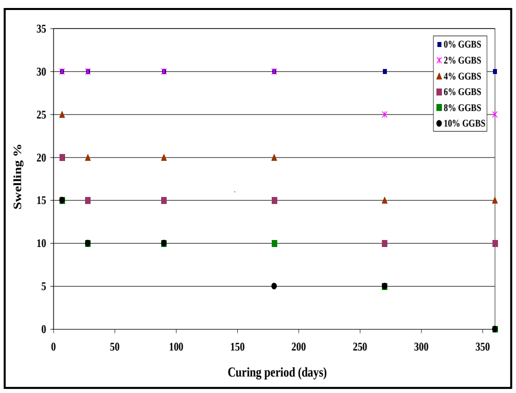

Figure 3.14 - Effect of GGBS (%) on the free swelling of the test soil, cured under CC2 conditions, at different curing periods

3.3.3Effect of GGBS Activated by Lime on the FS% of the Test Subgrade Soil

Two curing conditions and periods, 7 and 28 days, were employed in this study of the effect of GGBS activated by lime on the FS% of the test soil. Figures 4.17 and 4.18 illustrate the effect of total binder, with different lime/GGBS ratios, on the FS%, for samples cured under CC1 and CC2 conditions, after 7 and 28 days. It can be observed that, percentage of FS% decreases with increasing the total binder content for constant lime/GGBS ratio, with an increase in lime/GGBS ratio at constant binder content, with increasing the curing temperature keeping the binder content and lime/GGBS ratio constant, and with increasing the curing period keeping all other parameters constant.

Finally, it can be concluded that:

1. The addition of GGBS alone to the test soil decreased the FS% significantly. The FS% decreased with increases in the GGBS content, curing periods and temperature.

2. The addition of GGBS and lime to the test soil decreased the percentage of FS% dramatically. The FS% decreases with an increase in the total binder content, the lime/GGBS ratio, curing periods and the temperature.

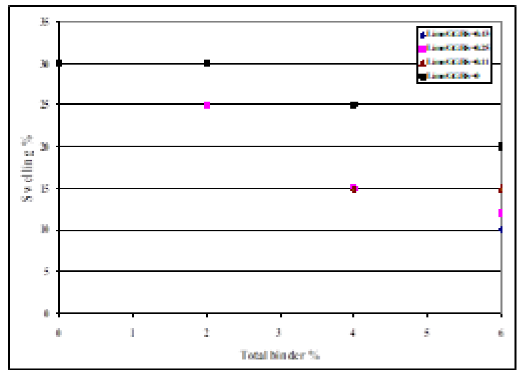

Figure 3.15 - Effect of GGBS and lime on the free swelling percent of the test soil, cured under CC_1 conditions, after 7 days

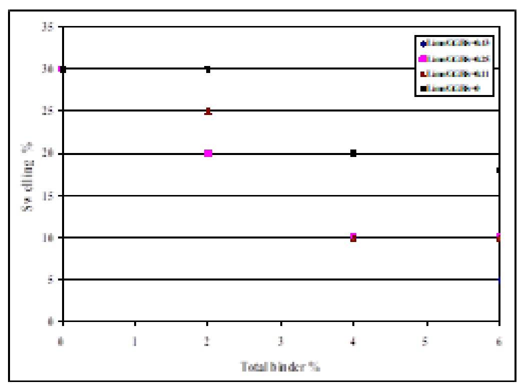

Figure 3.16 - Effect of GGBS and lime on the free swelling percent of the test soil, cured under CC_1 conditions, after 28 days

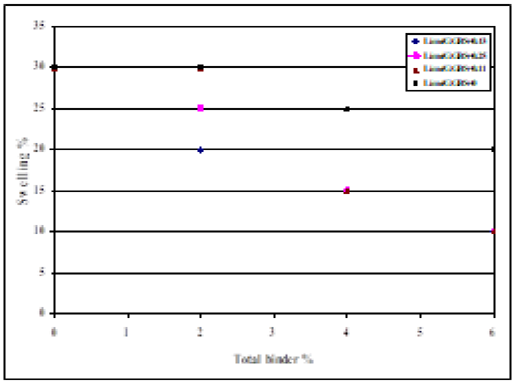

Figure 3.17 - Effect of GGBS and lime on the free swelling percent of the test soil, cured under CC_2 conditions, after 7 days

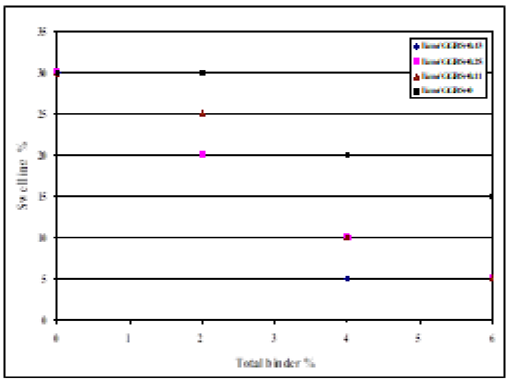

Figure 3.18 - Effect of GGBS and lime on the free swelling percent of the test soil, cured under CC_2 conditions, after 28 days

4. Conclusions

The results were discussed and concluded, as follows:

1. The addition of GGBS activated by lime has a small effect in compaction properties, a decrease in the MDD and an increase in the OMC. An increase in lime/GGBS ratio leads to further increases in the OMC and small increases in the MDD.
2. Adding GGBS activated by lime dramatically increased the UCS of the test soil with an increase in binder content, the lime/GGBS ratio, the curing period and temperature.
3. The addition of GGBS activated by lime decreased the FS% of the test soil. The FS% decreased with an increase in the binder content, lime/GGBS ratio, curing period and temperature.

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