GLOBAL JOURNAL OF ENGINEERING, DESIGN & TECHNOLOGY
(Published By: Global Institute for Research & Education)
www.gifre.org

CHARACTERISTICS OF STABILIZED SHRINK-SWELL DEPOSITS USING EGGSHELL POWDER

E. Nyankson[1, 2], B. Agyei-Tuffour[1, 3], E. Annan[1, 3], D. Dodoo-Arhin[1], A. Yaya[1], L. D. Brefo[1], E. S. Okpoti[1] & E. Odai[4]

[1]Department of Materials Science and Engineering, University of Ghana, Private Mail Bag, Legon-Accra, Ghana
[2]Department of Chemical Engineering, Auburn University, 212 Ross Hall, Auburn-Alabama, USA
[3]Department of Materials Science and Engineering, African University of Science and Technology, Abuja, Nigeria
[4]National Materials Laboratory, Ghana Highways Authority, Accra-Ghana

Abstract

Shrink-swell soils expand and heave or contract and crack during periods of high and low moisture contents. The expansion and contraction cause the lifting and or sinking of structures, crack development and eventual collapse of engineering structures. The need to stabilize such plastic soils to improve their load carrying capacities cannot be overemphasized. Therefore in this article, the effect of lime contained in eggshell and its application in the stabilization of shrink-swell soils have been explored. 4wt% and 8wt% of eggshell powder were mixed with equal masses of two different soil samples from Dodowa (DD) and Adalekope (AD) in Ghana. The samples were characterized with x-ray florescence (XRF), Plasticity Index analysis (PI), Free Swell Index (FSI), pH test and grading test. The x-ray florescence results showed that eggshell contains about 52wt% of CaO, which is largely responsible for the soil stabilization. The sample mixed with 8wt% eggshell powder show a decrease PI, FSI and a high silt/clay fraction. The results obtained have been discussed and can influence the application of eggshells powders for large scale stabilization of expansive soils.

Keywords: *Expansive Soil; Eggshell lime; Plasticity Index; Free Swell Index, Soil Stabilization*.

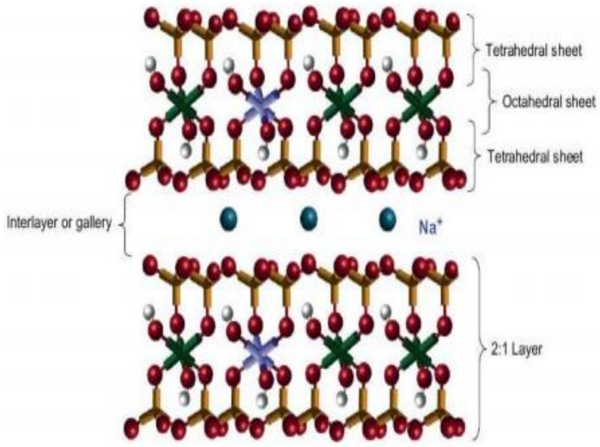
Introduction

Every engineering structure, such as buildings, bridges, highways, canals and dams requires a suitable foundation for optimum performance without failure. Shrink-swell soils depending on the amount of moisture in the ground will experience changes in volume of up to thirty percent (30%) and the associated damages can be very extensive. That makes expansive clay soils a natural hazard that ranks with hurricanes, earthquakes and floods in regards to overall cost Holtz, (1959). Some of them include lifting, sinking, crack development and collapse of the structure resting on those foundations. The soil loses strength and experiences instabilities. The effect of this is often translated to the structures resting on them. The expansion potential of any particular soil is determined by the percentage and the type of clay in the soil. Clay particles which cause soils to be expansive are extremely fine usually less than 2µm. Their shape is determined by the arrangement of their constituent atoms which forms thin clay crystals. The actual clay crystals are a composite of aluminum and silicon sheets which are held together by intra-molecular forces as reported by Yaya *et al*. (2012). For a group of prominent and highly expansive clay minerals called smectites, one octahedral sheet is sandwiched between two tetrahedral sheets to create the mineral structure. In expansive clays, groupings of the constituent clay crystals will attract and hold water molecules between their crystalline sheets in a sort of "molecular sandwich". According to Yaya et al, (2012), the clay mineral "montmorillonite", which is the most notorious in the smectite family, can absorb very large amounts of water molecules between its crystalline sheets also called galleries in a process termed intercalation] and therefore has a large shrink-swell potential. Chemically it is hydrated sodium calcium aluminium magnesium silicate hydroxide $(Na, Ca)_{0.33}(Al, Mg)_2(Si_4O_{10})$ (OH)2$\cdot nH_2O$. Potassium, iron, and other cations are common substitutes; the exact ratio of cations varies with source. As shown in Figure 1a. From Braja (2006), the liquid limit and plasticity index gives an indication of the type of soil. The diagram in Figure1b is the Cassagrande Plasticity Chart used to determine the type of soil based on the liquid limit (LL) and plasticity index (PI) values. All soils on and above the A- line are considered clayey soils whereas those below are non-clayey soils. Those high above the A- line are expansive clayey soils with high plasticity.

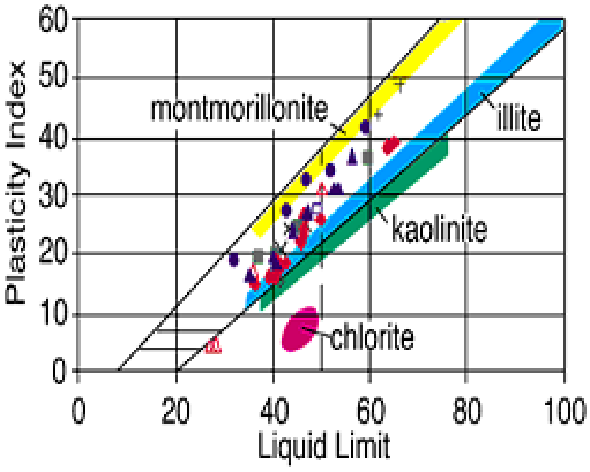
When potentially expansive soil becomes saturated, more and more water dipoles are gathered between the crystalline clay sheets, causing the bulk volume of the soil to increase or swell. The incorporation of the water into the chemical structure of the clay will also cause a reduction in the capacity or strength of the soil. During periods when the moisture in the expansive soil is being removed, either by gravitational forces or by evaporation, the water between the clay sheets is released, causing the overall volume of the soil to decrease or shrink. As the moisture is removed from the soil, the shrinking soil can develop gross features such as voids or desiccation crack. These shrinkage cracks can be readily observed on the surface of bare soils and provide an important indication of expansive soil activity as presented in Figure 1c.

To mitigate this effect, soil stabilization is adopted and in one form, the upper several feet of expansive soils may be removed and new non-expansive material imported and compacted to create a stable layer of soil at the building footprint whereas on the other, depending on the severity of expansion potentials, a non-expansive soil may be mixed with expansive soil to lower the expansion potential to an acceptable level according to Odai *et al*., (2004). There are also expansive soil chemical treatments available which are designed to alter the clay mineralogy and reduce the expansion potential. Eggshells have been recently identified to have the potential of stabilizing expansive soils due to its high lime content according to Amu et al., (2005). The addition of eggshell powder alters the foundation soils to conform to desired characteristics and also improves its strength and durability as reported by Planikumar, (2009). Other properties such as soil density increase, increase in cohesion, frictional resistance and reduction in plasticity index that can support different loads have been reported. The treatment with lime or calcium oxide is the most traditional method and eggshell powder's chemical composition is similar to that of limestone. In an article by Tocan, (1999), eggshell primarily contains calcium, magnesium carbonate and protein and the quantity of lime in eggshell is almost the same as in limestone on ton for ton basis.

Ghana has enormous clay deposits with varying silt and moisture contents on which there are many structures such as buildings, bridges, highways etc. These soils could also be used for other industrial applications if they are stabilized. Two common deposits with high degrees of expansivities are the Dodowa deposits and the Adalekope deposits in the Greater Accra region of Ghana which is experiencing major constructional activities following the discovery and exploitation of crude oil in commercial quantities. With the addition of eggshell powder as a supplement or a substitute to limestone, the stabilization effect of the eggshell powder could be understood and adopted the in the construction industry.



(a) Montmorillonite structure (Yaya *et al, 2012*)



(b) Plasticity Chart

(c) Shrinkage cracks of expansive clays

Figure 1a-c: Show the chemical structure of Montmorillonite, Cassagrande Plasticity Chart of clays and Shrinkage crack

Materials and Methods

Sample Preparation

The expansive soil samples were air-dried and the lumpy ones broken down before various tests were conducted on them. The natural moisture content of each sample was determined prior to the various tests. This was done to know the natural state of the expansive soil samples before adding the lime and eggshell. The eggshell samples were also dried for 7days and ground into eggshell powder by ball-milling. The powdered samples including the limestone were passed through a 425µm sieve to obtain a uniform particle size of the powdered eggshell and limestone.

Chemical Composition of AD, DD and Eggshell Samples

X-ray fluorescence (XRF) analysis were conducted on the expansive soil samples, the limestone powder and the eggshell powder to serve as a reference point for measuring the effects of the various additives on the expansive soil. The powdered limestone and eggshell samples were first sieved through a 106μm-180μm sieve to obtain uniform particle sizes. 4g each of AD and DD were mixed with 0.9g of Licowax powder into a disk a mixer machine for 3 minutes at a frequency of 15.0Hz. The sample was then pressed with a load of 10^4kg into a pellet for analysis in the XRF chamber. Batch formulations of the lime-soil, eggshell-soil and lime-eggshell-soil combinations were prepared. The weights were specific to the requirements of the types of tests which they were used to conduct as shown in Table 1.

Table 1. Batch formulation of expansive soils mixed with eggshell powder and lime in their respective proportions

Sample	wt % DD	wt % Eggshell	Sample	wt % DD	wt % Lime
ADE-0	100	0	ADL-0	100	*0*
ADE-4	96	4	ADL-4	96	*4*
ADE-8	92	8	ADL-8	92	*8*
DDE-0	100	0	DDL-0	100	*0*
DDE-4	96	4	DDL-4	96	*4*
DDE-8	92	8	DDL-8	92	*8*
ADE2-L6	92	2-6	DDL2-E6	92	*2-6*
ADE4-L4	92	4-4	DDL4-E4	92	*4-4*
ADE6-L2	92	6-2	DDL6-E2	92	*6-2*

The soil samples were sieved through a 2mm aperture sieve size. 20g of the soil samples were weighed into containers. 20g batch of each of soil-lime and soil-eggshell combinations were put in containers. 20ml of water was added to each batch by means of a measuring cylinder and stirred continuously for 30mins and allowed to settle for 30minutes. The pH readings of each sample were taken and recorded.

The pulverized soil samples were passed through a 425μm IS Sieve and oven-dried. Two specimens of lime-soil and eggshell-soil mixtures of 10g each were prepared. Each soil specimen was poured into a graduated glass cylinder of 100ml capacity. Distilled water was poured in one and kerosene in the other cylinder up to 100ml mark. Entrapped air was removed by gently shaking or stirring with a glass rod. The suspension was allowed to attain the state of equilibrium (for not less than 24hours). The final volume of soil in each of the cylinders was read out and the free swell index calculated as follows.

$$FSI = \frac{V_w - V_k}{V_k} \times 100\% \quad \text{...}(1)$$

where, FSI is the Free Swell Index, V_d is the volume of soil specimen read from the graduated cylinder containing distilled water and V_k is the volume of soil specimen read from the graduated cylinder containing kerosene.

Plasticity Index of Samples

Plasticity Index is the numerical difference between the liquid limit and the plastic limit for a particular material and indicates the magnitude of the range of moisture content over which the soil remains plastic. The Cassagrande device, ELLE international was used for plasticity index (PI) testing. It has a cup and grooving tool and is mechanically operated. Equation (2) below was used in the computations.

$$PI = LL - PL \quad \text{..}(2)$$

Where PI is the Plasticity Index, LL is liquid limit and PL, plastic limit.

Grading or Sieving Test

The soil sample was cone and quartered with a riffling box and about 500g weighed and sieved with British Standard (BS) test sieves of range 19-0.075mm. The mass of sample retained on each sieve as well as their moisture contents were weighed and recorded. The remaining mass passing was soaked for at least 16hr after weighing. The sample was washed and oven dried at 110^{o}C. The dried sample was sieved using the mechanical shaker for 30minutes. The percent of aggregate passing through each sieve was determined using equation 3.

$$\%\mathrm{R} = \frac{W_{sieve}}{W_{total}} \times 100\% \quad \text{...…}(3)$$

Where R is weight retained, W_{sieve} is the weight of aggregate in the sieve and W_{total} is the total weight of the aggregate.

Results and Discussion

Figure 2 presents the XRF analysis of the soil samples. The SiO_2 content in AD and DD samples were 48.73% and 64.77% respectively. It is observed that DD has about 20% more of SiO_2 than AD and this explains why the DD showed high amounts of sand fractions in the grading test. Also, the initial CaO content of 1.88 in AD was observed compared to a marginal 0.20 wt% in DD. This might have aided the relative stabilization process in the former as the Initial Consumption of Lime (ICL) was observed at 4% compared to 8% in the latter. From Figure 3, AD and DD showed PIs of 34 and 16 respectively which make them clayey soils and therefore expansive soils. This agrees with the report according to Odai, (2009) which stated that soils with PI greater than 10 are potential clayey soils. The free swell indices were also reported for AD and DD to be 77 and 16 respectively. The elemental analyses of limestone and eggshell showed appreciable amounts of CaO as shown in Figure 4. The amounts in limestone and eggshell were 62.90 and 52.97wt% respectively with CaO content about 16% higher in limestone than in eggshell and therefore, eggshell could be used to supplement lime, a potential substitute for limestone and a reliable stabilizer in expansive soils.

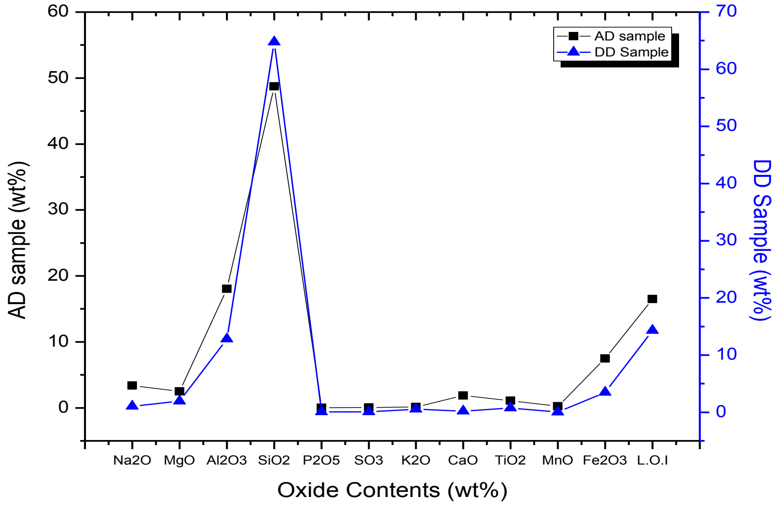


Figure 2 presents the comparative XRF analyses of Adalekope (AD) and Dodowa (DD) expansive soil samples

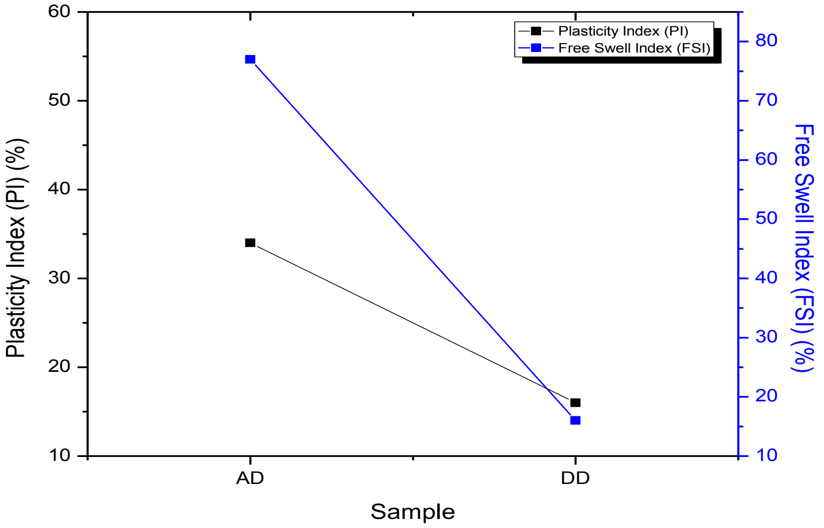


Figure 3 shows the Plasticity Index and Free Swell Index of AD and DD samples

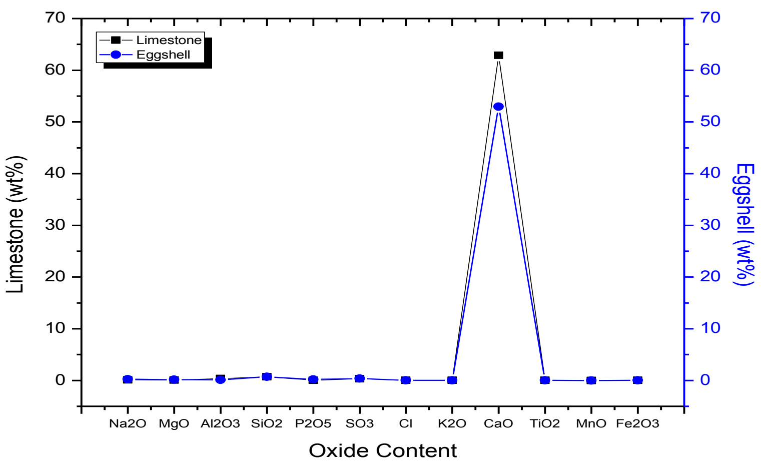
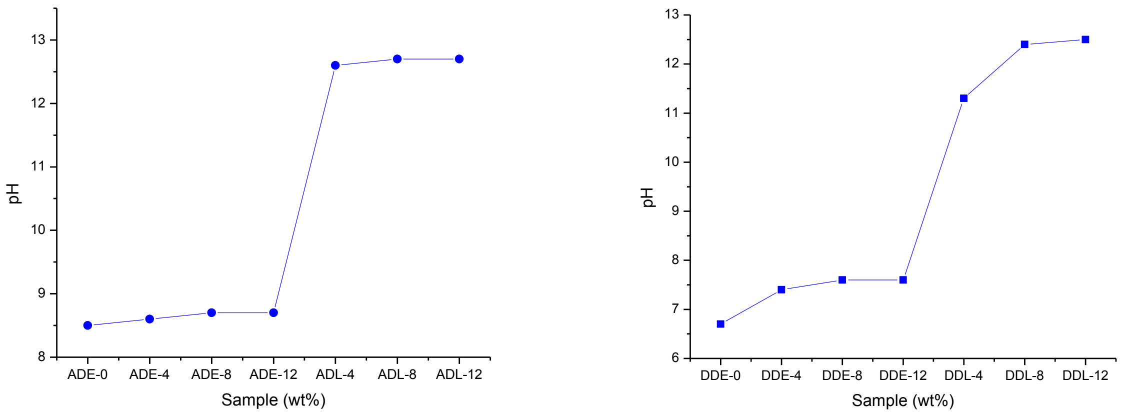


Figure 4 presents the comparative XRF analyses of Limestone and Eggshell Powder

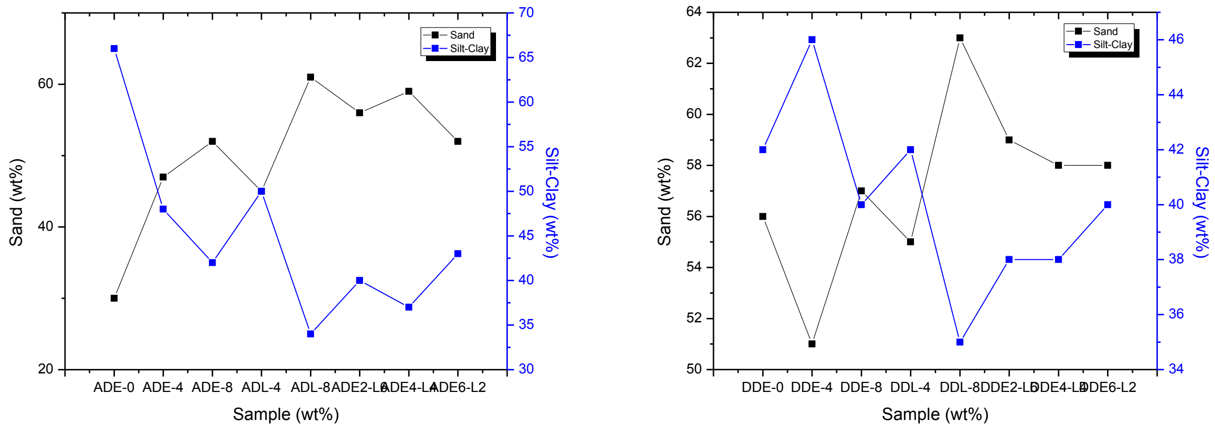
Figure 5a-b shows the pH results for AD and DD with the eggshell and lime compositions and Figure 6 presents the sand and silt-clay content of sample AD and DD. It is observed that the addition of eggshells recorded a relatively low pH, between 8 and 8.6 for AD and between 6.5 and 7.5 for DD. The addition of lime recorded a constant pH of about 12.5 for AD and between 11.5 and 12.6 for DD. From figure 6a, it was expected that effective stabilization would occur at a maximum of 8wt% for both lime and eggshell. The raw samples (ADE-0, ADL-0) had clay content as high as 66% and 59% respectively. Clayey fractions are responsible for the absorption of water and thus increasing the tendency for expansion. According to Planikumar (2009), when lime is added to expansive clay, complex chemical reactions take place. At the colloidal level, Base Exchange occurs with the strong calcium ions of lime replacing the weaker ions such as sodium on the surface of the clay particle. Further adsorption of non-exchanged calcium ions also lead to an increase in ion density. This results in a change of soil texture through flocculation of clay particles that reduces clay content and increases the percentage of coarse particles. It is again observed from figure 6a that, at 4wt% (ADL-4) and 8wt% (ADL-8) lime content decreases in the clay fractions were recorded with corresponding increases in the sand fractions. This could be attributed to the flocculation-agglomeration action of lime on the clay fractions. This caused a substantial amount of these particles to increase in size leading to an increase in the sand fractions from 30% in the raw material to 45% at 4wt% eggshell (ADE-4) and 61% at 8wt% eggshell (ADE-8). Also at 4wt% and 8wt% eggshell compositions, decreases in the clay fractions and corresponding increases in the sand fractions were observed. At 4wt% eggshell, the clay fractions decreased from an initial 66% in the raw sample to 48% with increase in the sand fraction from 30% to 47%. The batch containing lime-eggshell combinations also showed decreases in the clay fractions and corresponding increases in the sand fractions although these changes were of low magnitude.



(a) (b)

Figure 5a-b presents the pH analysis of ADE, ADL, DDE and DDL samples based on eggshell powder and lime compositions

Figure 6a-b presents the effect of lime and eggshell compositions on the sand and clay fractions of AD and DD. Compositions of sand (56%) and clay-silt (42%) were recorded respectively for DD. The Optimum stabilization occurred at 8wt% lime (DDL-8) which recorded 2%, 3% and 35% for gravel, sand and clay respectively. From Figure 6a, it is observed that sample DD was sandier because the sand fractions in the raw sample which stood at 56% exceeded the clay fractions of 42%. The clay fractions are water absorbing and are responsible for the expansive nature of the soil. Due to the nature of sample DD, the effect of the stabilization by eggshell powder and lime were not clearly evident although there were small decreases in the silt/clay fractions with corresponding increases in the sand fraction across the batches, these changes were generally not significant except at 8wt% lime where a decrease in the clay/silt fraction to 35% was observed. The FSI for the soil showed decreases in the various batches from 77% for the raw sample to 30% and 33% for 8wt% lime DDL-8 and DDL6-E2 respectively. From Figure 7a, it is observed that, the lime showed a sharp decrease in FSI as compared to the eggshell which showed marginal decreases in FSI. The increase in FSI for the lime-eggshell combinations for DDL4-E4 and also DDL2-E6 is a result of the excess CaO which again tends to absorb water and increase the volume. The decrease in FSI at DDL-8 is the result of the gradual replacement of highly negative ions on the surface of the clay structure. This reduced the water absorption ability and thus decreased the swelling potential. The raw sample showed a lower FSI of 16%. The FSI for the various samples showed decreases in the various batches from 16% to 6% and 7% for DDL-8 and DDE-8 respectively. Eggshell-lime combinations did not however show appreciable decreases in FSI. The swell potential of every soil sample greatly depends on the clay/ silt portion of the soil.



(a) (b)

Figure 6a-b Sieve and Grading test analysis of DD and AD with eggshell and lime composition

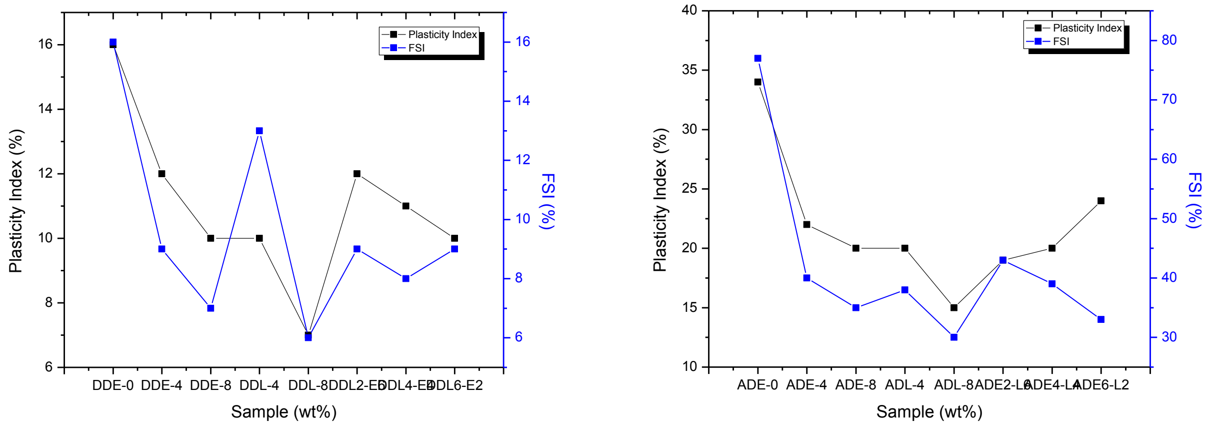


Figure 7a-b presents the effect of eggshell and lime contents on the Plasticity Index (PI) and Free Swell Index (FSI) of DD and AD samples respectively.

From the results of the sieve analysis of Figure 6a-b, it is realized the raw sample DD contained less clay/ silt fractions of 42% and this is responsible for the low free swell index values recorded for this sample. The PI of the sample AD was 34 indicating that the clay is of high plasticity. The PI of this batch decreased remarkably to 15 in ADL-8. According to Croft, McGeory and Carlson, (1999), high plasticity is an indicator for swelling potential. Clay is susceptible to large volume changes if the PI is greater than or equal to 30. From figure 7b, the PI of this batch decreased remarkably due to the replacement of water absorbing ions of the clay by the lime which decreased the water absorption ability characterized by the reduction in Liquid limit and a further decrease in the PI. The PI of ADL-4 however increased further due to the extra water that needed to be replaced by the insufficient lime which makes the soil to swell.

The sample ADE2-L6 recorded a higher PI compared to that obtained for the optimal mixture of lime ADL-8. An optimal batch was achieved in ADL6-E2 with the PI of 19%, indicating that the addition of eggshell powder had a positive effect on the PI when compared with the PI of sample 4wt% lime, but was not as effective as the optimal mixture of lime. The PI of the raw sample AD was 16% but decreased remarkably to 7% in ADL-8 and also appreciable decrease in PI was observed in ADE-8 and in ADL6-E2. From the raw sample, it is realized that the PI of the sample is quite low and thus very low PIs was observed across the batches with a minimum PI of 7 at 8wt% lime. It again implies an optimum PI is recorded at this same composition. From Figure 7a-b, the eggshell and lime-eggshell combinations, recorded an optimum of 10% PI at ADE4-L4 and also in ADL6-E2. This indicated a positive effect of the eggshell and eggshell- lime combinations on the stabilization potential in shrink-swell soils.

Conclusions

From the results of the chemical analysis, it is observed that although both AD and DD were clayey soils, sample AD was much more clayey and potentially expansive than sample DD. Less silt/clay fractions were observed in the latter. The chemical analysis showed clearly that this sample was more sandy than clayey. The large difference in PI and FSI for both raw samples confirms the degree of clay in both samples. It is observed that lime possesses greater stabilizing potential than eggshell however considering that the increase in CaO of limestone over eggshell is only about 16% and this provides a basis for eggshell powder as a reliable source of lime for expansive soil stabilization. The effectiveness of the eggshell was observed across the various tests as decreases in PI and FSI were observed for 4wt% and 8wt% in all the sample types. Also from the grading analysis, decreases in clay/silt fractions were observed for 4wt% and 8wt% eggshell in both AD and DD.

Future Work

It is recommended that the following test should be carried to enhance the understanding of the stabilization of shrink swell soils;

- The various tests showed different responses to the batches and therefore, further studies should be conducted into the stabilization process by using calcined eggshell powder. Calcination will improve the eggshell concentrate and will enhance the stabilization studies.
- Further studies will conducted to established the "lime demand (ICL)" for the eggshell and compared with that of lime for standardization.
- The SEM microstructure to ascertain the distribution of the lime/eggshell powder in the stabilized samples will be investigated.

Acknowledgements

The authors thank the Ghana Highways Authority, Council for Scientific and Industrial Research, (CSIR) for making their laboratories available to us. We are also grateful to the Department of Materials Science and Engineering, University of Ghana for the funding.

References

Amu, O. O. Fajobi, A. B and Oke, B.O., 2005. Effect of Eggshell Powder on the Stabilizing Potential of Lime on an Expansive Clay Soil. Department of Civil Engineering, Obafemi Awolowo University, Ile- Ife, Nigeria. Research Journal of Agriculture and Biological Sciences 1(1): 80-84.INSInet Publication.

Braja M. Das, Principles of Geotechnical Engineering.5th Edition, 2006

Croft C. P., McGeory and D.H Carlson, 1999. Physical Geology, 8th edn. McGraw Hill companies Inc. New York, pp: 48-56.

Holtz, W.G., 1959. Expansive Clays- Properties and Problems. Quarterly, Colorado School of Mines, Volume 54, No.4.

Odai, E.L., Lime Stabilization of expansive Subgrade Soil, MSc. RTECH, KNUST, (2009).

Planikumar, B.R., 2009. Effect of Lime and Fly Ash on Swell, Consolidation and Shear Strength Characteristics of Expansive Clays: A Comparative Study. Geomechanic and Geoengineering: An International Journal, Volume 4, No. 2, 175-181.Taylor and Francis Group.

Tocan, A. G. J., 1999. Utilization of Chick Hatchery waste: The Nutritional Characteristics of Day Old Chicks and Eggshell, Agricultural Wastes, 4:335-343.

Yaya A. *et al*, Layered Nanomaterials - A Review, Global Journal of Engineering Design and Technology, Vol. 1(2), 32-41. 2012

Zonberg, J. G, Kuhn, J. A. and Plaisted, M. D., 2009. Characterization of the Swelling Potential of Highly Plastic Clays using Centrifuge. Technology Center for Transportation Research, University of Texas at Austin.