Comparison of the Stabilization Behavior of Fly Ash and Bottom Ash Treated Expansive Soil

T.B.C.H. Dissanayake, S.M.C.U. Senanayake and M.C.M. Nasvi

Abstract: Expansive soil swell on absorbing water and shrink when that water gets evaporated. Because of this alternate swelling and shrinkage of expansive soil, the civil engineering structures built on them get severely damaged. Ground improvement using mechanical and chemical methods can be a mitigation measure. In this research, chemical stabilization was used as a ground improvement technique. The variation of the compaction characteristics, Atterberg limits, Unconfined Compressive Strength (UCS) and swell pressure were tested using separately ASTM Class F fly ash (low calcium) and bottom ash as chemical stabilizers at 8 %, 16 % and 24 % of the total weight of the expansive soil. A Scanning Electron Microscopy (SEM) test was also conducted to study the microstructural changes in the expansive soil treated with fly ash and bottom ash. The results indicate that the Maximum Dry Density (MDD) of the stabilized soil increases up to 16 % with fly ash and bottom ash additions and that it begins to decrease thereafter with further additions. The results of the Atterberg limits test reveal that the liquid limit and the plasticity index decrease with both fly ash and bottom ash additions while the plastic limit increases with those additions. The effect of fly ash and bottom ash on the variation of the UCS was observed for three different curing periods (7, 14 and 28 days) as well as for three different percentages of ash content (8 %, 16 % and 24 %). The findings reveal that the UCS increases up to 16 % of ash addition, and that it thereafter starts to decrease with any further addition of fly ash or bottom ash. Furthermore, an increase in the curing period will help to increase the UCS for a given percentage of additions. The microstructure of the stabilized soil becomes more uniform as the optimum ash content is reached, and beyond this optimum value, the microstructure becomes nonuniform with an abundance of unreacted ash particles. A reduction of the swell pressure by 70% for fly ash and 48% for bottom ash is observed with the addition of admixtures. The main conclusion that can be drawn from this study is that the MDD, UCS and the plastic limit can be increased with the addition of fly ash and bottom ash while swelling, liquid limit and plastic index can be reduced through these additions. Fly ash is also found to be more effective than bottom ash in stabilizing expansive soil.

Keywords: Bottom ash, Fly ash, Expansive soil, Swell Pressure, Uniaxial Compressive Strength.

1. Introduction

Expansive soils are those which undergo a considerable volume change with the addition or removal of water. The major components of expansive soils are kaolinite, montmorillonite, and illite group soils [1]. This type of soil has low bearing capacity, high settlement, low shear strength and high water absorbability. High plasticity clay and expansive clay are some of the examples of this type of soil [2]. Several problems arise when civil engineering structures are constructed on expansive soils because of their low bearing capacity. These soils have a high water content and when the ground is loaded, this water gets expelled giving rise to consolidation settlements. In addition, due to the low shear and compressive strength, shear failure will also take place [3].

The engineering properties of expansive soils can be improved by soil stabilization

methods. These methods can be divided as mechanical and chemical methods. The mechanical methods include soil replacement, densification and compaction (vibroflotation), hydraulic modification using vertical drains and surcharge loads [4]. In chemical stabilization, soil is stabilized by adding different chemicals. The main chemical stabilizers that are added to the soil are cement, lime, fly ash, bitumen and chemical compounds [5].

*Mr.T.B.C.H.Dissanayake, Student Member of IESL, B.Sc.Eng. (Hons.)(Peradeniya), Department of Civil Engineering, University of Peradeniya.
Email:charith035@gmail.com*

*Mr.S.M.C.U.Senanayake, Student Member of IESL, B.Sc.Eng. (Hons.) (Peradeniya), Department of Civil Engineering, University of Peradeniya.
Email:udaya1senanayake@gmail.com*

Eng.(Dr.)M.C.M.Nasvi, AMIE(Sri Lanka), B.Sc. Eng. (Hons.) (Peradeniya), PhD (Monash), Senior Lecturer of Civil Engineering, Department of Civil Engineering, University of Peradeniya. Email:nasvimcm@pdn.ac.lk

The combustion of coal in coal power plants generates solid waste such as Fly Ash (FA) and Bottom Ash (BA). If these by products are not properly utilized, they can cause severe environmental problems. In this research, fly ash and bottom ash were used for stabilizing expansive soil. The Norachcholaï coal power plant in Sri Lanka produces around 75,000 tons of FA and BA annually, out of quantity only a small amount of FA is used in construction activities including cement manufacturing.

The remaining solid waste is dumped in landfills, causing environmental problems and incurring additional costs for landfilling. The use of these materials to stabilize soil can be a sustainable solution when considering the large quantities of waste produced. Therefore, this study focused on the chemical stabilization of soft soil using FA and BA as admixtures. The burning of coal results in two type of ashes; (1) one type consists of very fine particles which are transported by flue gases and this type is called FA and (2) the other type is a product of burning consisting of somewhat large particles settled at the bottom of the furnace and is called BA. FA can be classified as low calcium FA (ASTM Class F) or high calcium FA (ASTM Class C). According to the American Society for Testing and Materials (ASTM), the ash containing $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ at an amount exceeding 70% percentage by weight are defined as Class F, while those with a $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ content between 50% and 70 % by weight are defined as Class C.

There have been many studies done [4-10] focusing on the stabilization behavior of soft soils using various chemical admixtures. A summary of these previous studies in this area is given in Table 1.

In Sri Lankan context, there is no studies comparing stabilization behavior of expansive soil treated with FA and BA obtained from Norochcholaï coal power plant. Therefore, this research study focuses on the stabilization behavior of expansive soil mixed with various

2. Materials and methods

In this research, expansive soil was stabilized using FA and BA. The expansive soil sample was collected from Nikkakatiya, Digana, Sri Lanka. FA and BA were provided by Holcim Lanka Ltd, Colombo, Sri Lanka. To identify the swelling potential of the natural soil selected, a free swell test was conducted. The test results showed that the average value of the free swell ratio of the soil was 1.55. Thus the soil can be classified as moderately expansive soil [11]. The particle size distribution was determined through a sieve analysis and the gradation curve obtained is shown in Figure 1. In addition, the consistency limit test was also conducted to classify the soil. According to the Atterberg limits test, the natural expansive soil sample had a liquid limit of 49% , a plastic limit of 22% and a plasticity index of 27%. Based on the plasticity chart and the particle size distribution, the soil can be classified as medium plasticity clay (CH). The chemical composition of FA and BA were as shown in Table 2 [12].

Table 1 - Summary of previous studies done on the chemical stabilization of soft soils

Author	Admixture Used	Test Methodology	Key Findings
Deng et al [6]	Sewage sludge and Class F FA	Low plasticity slit clay was stabilized Additives: 0%, 2%, 4%, 8%, 16% by weight. The pH value, Proctor compaction and UCS tests were conducted.	UCS values of the FA treated mixture are less than those of the sludge ash treated mixture due to the Si, Al and Fe percentages in the additives. Si, Al and Fe contribute to form calcium silica hydrate (CSH) and CSH gives higher UCS values. The pH value of FA treated samples are higher than that of sludge ash treated samples.
Fusheng et al [5]	FA and lime	High plasticity slit clay was used. FA composition: 0, 3, 6, 9, 12 and 15% by weight. Lime composition: 0, 1, 2, 3% by weight The Atterberg limit test, free swell ratio test , swell potential test and UCS test were among the tests carried out.	Liquid Limit (LL) decreases with FA and lime addition. Free swell value and swell potential reduce with FA and lime addition. This may happen due to the flocculation of clay particles by cation exchange. In addition, the flocculation reduces the water affinity of the natural soil. UCS value increases with the ash addition up to an optimum value and it begins to decrease thereafter.

Estabragh and Pereshkafti [8]	Lime, cement, coal ash	High plasticity clay was used. Compositions of (a) Lime = 5, 10%; (b) cement = 5, 10, 15%; and (c) coal ash = 5, 10, 15, 20%. Atterberg limit test, Proctor compaction test and cyclic wetting and drying were conducted.	LL and Plasticity Index (PI) decrease with lime content while they increase with coal ash and cement content. MDD and the swelling pressure reduce with the additive content. The MDD reduces due to the increase of the void volume by the flocculation process. The void volume increment reduces the unit weight. Lime shows an equilibrium state after the 2 nd cycle while cement shows its equilibrium state after the 4 th cycle. In addition, coal ash shows an irregular pattern when the number of cycles is increased.
Laxmikant and Tripathi[9]	Granulated Blast Furnace Slag (GBS) and FA	High plasticity silty clay was used. Percentages of GBS used = 3, 6, 9%. For each GBS composition, FA was added at 3, 6, 9 and 12%. Proctor compaction test, California bearing ratio test, etc. were done.	MDD decreases with the FA content in the FA-GBS mixture. MDD increases with the GBS content when the FA percentage is kept constant. OMC increases with both FA and GBS percentages due to the absorption of water. CBR value of the mixture reduces with the FA and GBS content.
Somaiya et.al., [4]	FA	Expansive clay was mixed with three different percentages of FA (15%, 20% & 30%). Atterberg limit test, Proctor compaction test and UCS test were among the methodologies used.	LL and PL reduce with the FA content. MDD decreases initially with FA addition up to a 15% and then it increases with any further additions. It is because the voids in the mixture are filled with the fly ash content up to 15% after which the addition of fly ash does not fill the voids. Therefore, it directly contributes to the increment of the maximum dry density. The UCS value increases up to an optimum value and any further addition of FA tends to decrease this optimum UCS value.
Taniya and Suit [7]	FA, BA and pond ash	Different percentages (10, 15, 20, 25 & 30%) of FA, BA and pond ash were mixed with high plasticity silty clay. Proctor compaction test, UCS test and the swell potential test were conducted.	PI reduces with the ash content. MDD and the OMC decrease with additive percentages. UCS value increases with the curing period, and this happens due to the pozzolanic reaction.
Scott and Ferguson [10]	Class C FA	High plasticity silty clay was mixed with class C FA. Tests included Proctor compaction test and swell pressure test.	MDD decreases with a delay in the compaction. Swell potential reduces with the ash addition due to flocculation.

Table 2 - Chemical composition of FA and BA

Composition	Percentage by Weight (FA)	Percentage by Weight(BA)
SiO ₂	52.03	46.1
Al ₂ O ₃	32.31	23.7
Fe ₂ O ₃	7.04	5.8
CaO	5.55	7.0
MgO	1.3	1.2
SO ₃	0.07	-
K ₂ O	0.68	1.2
Na ₂ O	0.43	0.2

plastic limit test were performed on the sample passing the 425 μ m sieve. Unconfined Compressive Strength (UCS) test (BS 1377, 1990 Part 7) was conducted to determine the compressive strength variation with the curing period of the expansive soil stabilized with FA and BA. The expansive soil samples stabilized with FA and BA were compacted to MDD at the OMC. Cylindrical UCS test samples of 76 mm in height and 38 mm in diameter were extruded from the compacted samples. The samples were cured at ambient temperature for 7, 28 and 45 days. Then the UCS test was done for each curing period at a strain controlled loading rate of the axial strain at 1%/min. For each data point, three samples were tested to ensure reproducibility.

Figure 1 - Particle size distribution of the expansive soil

In this study, a series of experiments was conducted to study the effect of FA and BA on the engineering properties of stabilized expansive soil. Expansive soil was mixed with FA and BA at 8 %, 16 % and 24 % by weight and natural expansive soil was tested as a reference sample. Standard Proctor compaction test (BS 1377, 1990, Part 4) was conducted to obtain the Maximum Dry Density (MDD) and the Optimum Moisture Content (OMC). To study the variation of the consistency limits of the stabilized samples, Atterberg limit test (BS 1377, 1990, Part 2) was conducted. For the Atterberg limit test, the first FA and BA mixed samples were compacted to MDD at the OMC. The compacted samples were cured at ambient temperature (28 °C) for 28 days. After 28 days, the samples were grinded and the samples passing the 425 μ m sieve were taken. Liquid limit test (Cone Penetrometer method) and

The swell pressure test (BS 1377, 1990, Part 5) was used to study the swelling behavior of the stabilized soil. Constant volume method was used in the swell pressure test. The Scanning Electron Microscope test (SEM) was conducted to study the micro structural variation of samples treated with FA and BA .

3. Results and Discussion

3.1 Index Properties

This test was done to identify the variation of consistency limits with FA and BA addition. The effect of FA and BA on the consistency limit is shown in Figure 2.

Figure 2 - Variation of consistency limits of (a) FA and (b) BA treated soils

From Figure 2, it can be seen that in both FA and BA treated samples, the Liquid Limit (LL) decreases with the increase in the ash content. For instance, in case of the FA treated sample, the liquid limit reduces by 20% and in the case of the BA treated sample, it reduces by 17% when the ash content is increased from 0 to 24%. On the other hand, the Plastic Limit (PL) of both FA and BA treated samples increases with the increase in the ash content. In the FA treated sample, the PL increases by 5% while in the case of the BA treated sample, the corresponding increment is 21%. As a result, the plasticity index is also reduced when the ash content is increased from 0 to 24%. The decrease of the liquid limit with the addition of FA and BA to the expansive soil is mainly caused by the addition of FA or BA, as they reduce the thickness of the diffused double layer of the clay particles. This helps to promote flocculation of the particles, and increase the coarser particle content by substituting finer soil particles with coarser FA or BA particles [13].

The increase of the plastic limit and the decrease of the plastic index are mainly due to the flocculation of the clay particles and due to the increasing number of coarse particles in the mix. In addition, the pozzolanic material added to the mix get involved in chemical reactions. At the

colloidal level, the base exchange occurs with the strong calcium ions of FA or BA replacing the weaker ions such as sodium on the surface of the clay particle. Furthermore, the adsorption of the non-exchanged calcium ions also leads to an increase in the ion density. This results in a change of the soil texture through the flocculation of clay particles that reduces the clay content and increases the percentage of coarse particles. This improves the workability and reduces the plasticity index [14].

3.2 Compaction characteristics

The standard Proctor compaction test was carried out to determine the variation of the OMC and MDD with the addition of FA and BA. The variation of the MDD with the ash content is shown in Figure 3.

Figure 3 - Variation of MDD with ash content.

According to Figure 3, FA and BA treated soil samples exhibit the same behavior. Initially the MDD value is increased up to 16% of ash addition and start reducing beyond that, and this is mainly due to the flocculation caused by FA and BA particles in the treated soil samples. Due to flocculation, soil particles pack well together leading to an increased MDD [15]. The reduction of the MDD value beyond 16 % is due to the unreacted FA and BA particles. In addition, the specific gravity of FA and BA are lower than that of expansive soil. When more and more amounts of FA and BA are added to expansive soil, the resulting mix will have a lower specific gravity leading to reduced MDD values [5].

The variation of the OMC with the ash content is shown in Figure 4. When the OMC variation is considered for FA and BA treated samples, it can be seen that both FA and BA treated samples exhibit the same trend. Initially, the OMC value decreases up to a minimum value, and this decrease is mainly

due to the cation exchange between the additives. Expansive soil decreases the thickness of the electric double layer and promotes flocculation in the sample.

Figure 4 - Variation of OMC with ash content

The flocculation of the treated soil particles shows that the water, additives and soil mixtures can be compacted with a lower water content. After reaching its minimum value, the OMC starts to increase for any further increase in the ash content beyond the optimum value (see Figure 4). This kind of behavior can be seen due to unreacted FA and BA particles absorbing more moisture leading to an increment of OMC [5].

3.3 Variation of UCS of the stabilized soils

The variation of the average UCS of FA and BA treated samples is shown in Figures 5 and 6 respectively. The standard deviation of UCS for FA and BA treated samples was in the range of 0-8%.

Figure 5 - Variation of UCS with FA treated soil

According to Figures 5 and 6, the UCS variation of FA and BA treated samples follows the same trend. Initially, the UCS increases up to 16% ash content and then it starts reducing with the

further addition of the ash content. The maximum increase in the UCS is 540% in the FA treated sample, while it is 310% in the BA treated sample.

Figure 6 - Variation of UCS with BA treated soil

In addition, it can be seen that FA performs better than BA, as it shows a higher strength gain in FA treated samples when compared to BA treated samples. This is due to the high contribution made to the pozzolanic reaction by FA because of its high surface area[16]. The optimum ash content for high strength is 16% and there is a reduction in the UCS beyond this optimum value. The reduction percentage beyond the optimum value for FA and BA treated samples are 21.8% and 17.5% respectively at a 24% ash content. The reduction in the UCS beyond the optimum value is due to the additional quantity of FA and BA acting as unbounded silt particles, which have neither an appreciable friction nor cohesion, causing a decrease in the strength [5].

3.4 SEM Test Results

An attempt was made to study the microstructural changes of the stabilized soil samples for various ash contents, and the SEM images of 8%, 16%, and 24% FA and BA treated samples are shown in Figures 7, 8 and 9 respectively.

(a)

(b)

Figure 7- SEM images for 8% (a) FA, (b) BA

(a)

(b)

Figure 9 - SEM images for 24% (a) FA, (b) BA

(a)

(b)

Figure 8 - SEM images for 16% (a) FA, (b) BA

From Figures 7 and 8, it can be seen that 16% FA and BA treated samples show more uniform products than those of 8% FA and BA treated samples, where some air voids can be seen for 8% ash treated samples. This is the reason for higher values of UCS observed for 16% ash treated samples. As the ash content increases up to 16%, more pozzolanic reactions take place between soil and ash leading to uniform products. When Figures 8 and 9 are compared, it can be seen that there are many unreacted ash particles in the 24% ash treated samples. These unreacted particles cause UCS reduction beyond the optimum ash content.

3.5 Swell Pressure

Figure 10 shows the variation of the swell pressure of stabilized expansive soil with the ash content. According to Figure 10, the swell pressure reduces with the increase in the FA and BA content. This is due to the enhanced pozzolanic reaction as well as the formation of Calcium Silica Hydrate (CSH) and Calcium Alumina Hydrate (CAH) with the increase in the curing time [5]. The reduction in the swell pressure of the FA treated sample is 70% while that of the BA treated sample is 48%. In addition, FA is more effective than BA in

reducing the swell pressure potential and is involved in more pozzolanic reactions compared to BA due to the variation of the chemical compound between FA and BA.

Figure 10 - Comparison of swell pressure with the ash type

4. Conclusions

The following conclusions can be made from the study carried out on the effect of Fly Ash (FA) and Bottom Ash (BA) on the stabilization behaviour of expansive soil.

- 1) With the addition of FA and BA to expansive soil, both the liquid limit and the plasticity index are decreased while the plastic limit is increased.
- 2) The Optimum Moisture Content (OMC) of FA and BA treated samples initially decreases up to a minimum value (16% for FA and 8% for BA addition) and then it starts to increase for any further increase in the ash content beyond the optimum value. In addition, the Maximum Dry Density (MDD) also increases up to 16 % ash addition and beyond that it decreases.
- 3) The UCS of stabilized expansive soil increases up to 16 % ash content and then it starts decreasing with any further addition of the ash content. In addition, the UCS increase is higher for FA treated samples when compared to BA treated expansive soil.
- 4) Based on the results of the swell pressure test, it can be concluded that both FA and BA can reduce the swell pressure of the stabilized soil. However, FA is more effective in reducing the swell pressure when compared to BA.
- 5) Both FA and BA can be used to stabilize expansive soil. However, FA performs better than BA as a stabilizer of expansive soil.

References

1. Puppala, A., Punthutaecha., K., D'Souza, N. (2003), Assessment of Fly Ash and Bottom Ash Stabilization Methods on Soft and Natural Expansive Soils, ACE, International Conference on Advances in Civil Engineering.
2. Hansgeorg, K., Berhane, G., (2006), Excavations and Foundation in Soft Soils, Edition 2006, pp 11.
3. Dujang, B. H., David, G. T., Arun, P., (2012), Prasad Handbook of Tropical Residual Soils Engineering Edition, CRC press: pp 139.
4. Somaiya, P., Zala, Y., Dangar, R., (2013); Stabilization of expansive soil using FA; Conference paper.
5. Fusheng, Z., Songyu, L., Yanjun, D., Kerui, C., (2008), Behavior of Expansive Soil Stabilized with FA, Natural Hazards, vol 47(3), pp.509-523
6. Deng-Frong, L., Kae-Llong, L., Huan-Lin, L., (2007) Comparison between Sludge Ash and Fly Ash on the Improvement in Soft Soil, " Journal of the Air & Waste Management Association 57.1 : pp 59-64.
7. Tanaya, D., Suit, K., (2014), Effect of Fly Ash on Geotechnical Properties of Local Soil Fly Ash Mixes Sample, International Journal of Research in Engineering and Technology 3.5: pp 507-51
8. Estabragh, A. R., Pereshkafti, M. R. S., (2012) Stabilized Expansive Soil Behavior during Wetting and Drying, " International Journal of Pavement Engineering 14.4: pp 418-427.
9. Laxmikant, Y., Tripathi, R. K., (2013) Stabilization of Soft Soil with Granulated Blast Furnace Slag (GBS) and Fly Ash (FA), " International Journal of Research in Engineering and Technology 2.2 (2013): 115-119. Journal of Pavement Engineering 14.4 : pp 418-427.
10. Scott, M., Ferguson, F., (2015) Stabilization of Soil with Self-Cementing Coal Ash, World of Coal Ash (WOCA) : pp 1-7
11. Holtz, W. G., Gibbs, H. J., (1956) Engineering Properties of Expansive Clays, Transactions ASCE 121, pp 641-677
12. Priyadarshena, T, Dissanayake, R, Mendis P. (2015), Effect of Nano Silica, Micro Silica, FA and Bottom Ash on Compressive Strength of Concrete, Journal of Civil Engineering and Architecture vol 9 : pp 1146-1152

13. Sivapullaiah, P. V., Prashanth, J. P., Sridharan A., (1996), Effect of FA on the Index Properties of Black Cotton Soil, Soils and Foundations vol. 36 (1996) no. 1 :pp 97-103
14. Phani Kumar, B. R. and Sharma, R. S., (2004) Effect of Fly Ash on Engineering Properties of Expansive Soils. Journal of Geotechnical and Geoenvironmental Engineering , 130(7), pp.764-767
15. Phanikumar, B., (2009), Effect of Lime and FA on Swell, Consolidation, and Shear Strength Characteristics of Expansive Clay. Comparative Study, Geomechanics and Geoengineering international journal,vol 4.2 : pp 175-181
16. Bell, F. G., (1996), Lime Stabilization of Clay Minerals and Soils, Engineering Geology,vol 42: pp 223-237