International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 7 (2017) pp. 1365-1370

The Influence of Geopolymer for Laterite Soil with Different Compaction Effort as a Soil Liner

Dr. Mazidah Mukri
Senior Lecturer, Faculty of Civil Engineering
Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia.

Nik Nurul Syuhada Nik Ab Aziz
Postgraduate Student, Faculty of Civil Engineering
Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia.

Abstract

Modern landfills are designed to prevent liquid from leaching out and entering the environment. However, if not properly managed, the leachate is at risk for mixing with groundwater near the site, which can have negative effects to the human and environment. Lining system is the most important part in a landfill area. The purpose of lining system is to minimize leachate egress and prevent ground pollution. The typical forms of lining system are clay mineral liners, geomembrane liners and bentonite enriched soil liner. In designing soil liner, it is important to compact it properly to achieve low hydraulic conductivity and high strength of soil. In this study, laterite soil is used as a soil liner which were stabilized by adding different percentage of geopolymer. Geopolymer is a material that can easily react with water which results into a powerful compaction aid giving a higher density for the same compaction effort. Hence, geopolymer is choose to mix with laterite soil. Different percentage of geopolymer were used which are 5%, 10%, 15% and 20%. This research was carried out in an attempt to see the difference of compaction parameters between two types of compaction effort for laterite soil mix with geopolymer. The outcome of this study give a positive results due to the potential of geopolymer to fulfill spaces that exist between soil particles. It is also found that geopolymer give influences to the resistance properties, hydraulic conductivity and the strength of soil.

Keywords: Laterite soil, geopolymer, compaction effort, optimum moisture content, maximum dry density, soil liner

INTRODUCTION

Soil liners are commonly used in the base of waste containment facilities. It has been used for many years as engineered hydraulic barriers for waste containment facilities. A low hydraulic conductivity is the key parameter in the design of liner to prevent the downward migration of contaminants into aquifers. Besides that, [1] exposed that a landfill liner should have low hydraulic conductivity, be resistant to shrinkage cracking and have suitable mechanical properties for structural integrity during construction and operation. According to [2], from their studies suggest proper soil set of values for basic soil properties in order to achieve a hydraulic conductivity lower than 10^{-7} cm/sec.

Fine grained soils are normally used as a barrier primarily because their particle size is small enough to limit the flow of fluids. Compacted soil liners, usually 0.6 m to 3 m thick, consist of natural soil which is recompacted in the field to obtain the desired hydraulic strength properties. Good engineering practice and quality assurance programs can result in good quality and low hydraulic conductivity soil liners [3]. The hydraulic conductivity of compacted soil liners depends on the soil mineralogy and the manner of placement of the liner. Examples of soil liners used in liner and cover systems are shown in Figure 1.

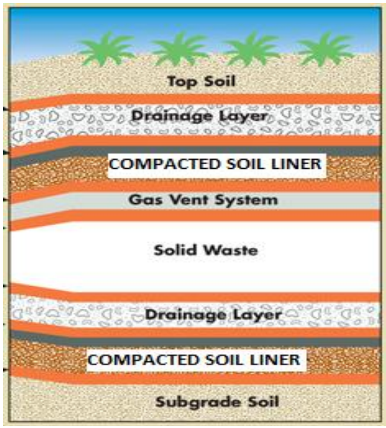

Figure 1: Examples of typical modern landfill (Source: [3])

Compaction

Compaction is defined as the reduction in soil void ratio by expulsion of air from the voids. Compaction occurs instantly with application of a force. Because compaction involves reducing the void ratio without changing the moisture content, the degree of saturation will increase [4]. Usually, the compactability of soil can be used as an example how moisture content, strength and management can interact. The wet soil has low resistance to structural change because it has a lower strength compare to dry soil. This is showed by the critical moisture content curve. For a given compaction force, the compaction effect increases as water content increases until to a point where the soil become so wet that the compaction will drops off. The critical moisture content for compaction occurs at the peak of the curve. There are a lot of factors that can affect the critical moisture content of the soil including soil texture and organic content of the soil.

In construction work of soil liner, compaction of soil is very important part because it is one of largest contributors to the site work economy. Large amount of construction cost are spent on compaction work. Therefore, it is necessary to control of compaction by using a material which can help reduce the compaction effort at site, thus reduce the cost of compaction. In addition, [5] stated that water content and compactive effort will affected the results of hydraulic conductivity. Increase in compactive effort applied to compact the specimen will result to low er hydraulic conductivity The main purpose of a laboratory compaction test was carried out to determine the proper amount of mixing water and suitable percentage of geopolymer to use when compacting the soil in the field and the resulting degree of denseness and low hydraulic conductivity which can be expected from compaction at optimum moisture content.

MATERIALS

This part will present the materials that were used. For this study, laterite soil was used as soil sample and geopolymer as an additive that is used to be added to laterite soil.

A. Laterite Soil

Laterite soil is one of the residual soils. Previous researcher [6] stated the term "*Laterization*" describes the processes that produce laterite soils. Lateritic soils usually develop in tropical and other regions with similar hot and humid climate, where heavy rainfall, warm temperature and well drainage lead to the formation of thick horizons of reddish lateritic soil profiles rich in iron and aluminium [7]; [8] and [9]). According to [6], a lateritic soil profile is characterized by the presence of three major horizons include the sesquioxide rich lateritic horizon, the mottled zone with evidence of enrichment of sesquioxide and the pallid or leached zone overlying the parent rock. Lateritic soils have a varieties colour from ochre through red, brown and violet to black. According to [10], the colour of the soils depends largely on the concentration of iron oxides and the presence of hematite and goethite. If soil sample consist high amount of iron oxides, the sample of laterite gives reddish to brown in colour.

In addition, [11] stated laterite soil are weathered under conditions of high temperatures and humidity resulting in poor engineering properties such as high plasticity, tendency to retain moisture and high natural moisture content. Laterite soils in the landfill area cannot perform satisfactory as barrier because of its high hydraulic conductivity. Hence, modification of soils to improve their engineering properties becomes necessary.

B. Geopolymer

Previous studies [12] and [13] mentioned that geopolymers are inorganic binders consisting of two components which are a very fine and dry powder, and a syropy, highly alkaline liquid. In order to produce a mixture of molasses like consistency which is then reacted with the desired waste or aggregate, the liquid and powder portions are mix together [12]. Refer to [13], they stated that in geotechnical applications, alkaline activation which is geopolymeric binder of fly ash was tested for soil improvement since waste material was obtained as binder in most of other geopolymer applications. Alkaline-activated materials showed better performance since durability and stability can be increased, improvement from mechanical aspect compared to cement and also improved bond between the soil particles and binder [14]. Alkaline activation generally was a reaction concerning alumina-silicate materials and alkali or earth substances alkali. At a molecular level to natural rocks, materials formed from reactions between silica, alumina and alkali cations were very alike in term of stiffness, durability and strength [13].

C. Fly Ash

Previous study [15] reported that fly ash is of coal fire by-product material from coal fired power station. Moreover, [16] acknowledged that fly ash is regularly used as a partial replacement for cement in concrete because of its pozzolanic properties. Besides that, it is also the form of ash, which has the greatest potential for use in ground modification. There are two classes of fly ash are defined by [17] which is Class F fly ash and Class C fly ash. The differences between these classes of fly ash are the amount of calcium, silica, alumina, and iron content in the ash. The chemical properties of the fly ash are largely influenced by the chemical content of the coal burned. Typically, class F fly ash is produced by burning of harder, older anthracite and bituminious coal. Class F fly ash contains less than 20% lime (CaO) and it is pozzolanic in nature. The additions of a chemical activator such as sodium silicate (water glass) to a Class F ash can lead to the formation of a geopolymer.

D. Sodium Hydroxide

Sodium hydroxide is one of the materials that are used to produce geopolymer binder. It consists in two different states which are in solution form or in pallet form. In a solution form, sodium hydroxide is a white, odourless, and non-volatile solution. It highly reactive but doesn't burnt. It reacts violently with water and numerous commonly encountered materials, generating enough heat to ignite nearby combustible materials [18]. The advantages of geopolymer are it can easily react with water which results into a powerful compaction aid thus giving a higher density for the same compactive effort. Sodium hydroxide reacts very effectively with soil rich in aluminium [18] and [19].

METHODS

The aim of this study is to know the best compaction effort with suitable percentage of geopolymer. The first section of this study describes the physical test to identify the type of soil sample and proceed with preparation of geopolymer. Then, compaction proctor test, which are Reduced British Standard Level (RBSL) and British Standard Light (BSL) test were carried to know compaction parameter of laterite soil mix with different percentage of geopolymer.

A. Preparation of Soil Sample

The soil that were taken from the site were prepared to be mix with geopolymer. The proportions of geopolymer that were used 5%, 10%, 15% and 20%. In the preparation of sample, five (5) different samples were prepared based on the different percentage of geopolymer. It includes one blank sample and four (4) other samples which laterite soil mix with 5%, 10%, 15% and 20% of geopolymer.

B. Preparation of Geopolymer

Geopolymers are inorganic binders consisting of two components which are a very fine and dry powder, and a syropy, highly alkaline liquid. Sodium hydroxide (*NaOH*) pellets were added to water to obtain sodium hydroxide solution. Varied percentages of geopolymer ranging from 5% to 20% were used to the soil sample. In research done by [12] the soil was oven dried and sieved down before being mixed with 87% of low calcium content (class F) fly ash and lastly the 8% of sodium hydroxide with 5% of water was added and mixed together.

C. Basic Properties Test

Experimental work were mainly carried out in Geotechnical Laboratory of Faculty of Civil Engineering UiTM, where the basic properties test were performed accordance with Bristh Standard BS 1377: Part 2: 1990. The tests that were carried out in this study including basic properties and engineering properties test. The basic properties test were conducted to determine the physical properties of soil sample such as Particle Size Distribution Test, Atterberg Limit Test, Specific Gravity Test and Linear Shrinkage Limit Test based on BS 1377: Part 2: 1990. Then, followed by compaction proctor test for natural soil and soil with various percentage of geopolymer.

D. Compaction Test

Compaction test were carried out using Standard Proctor Test in order to obtain optimum moisture content (OMC) and maximum dry density (MDD) of soil and soil mixture. In this test, different compaction test were done to the different percentage of geopolymer (Reduced British Standard Level and British Standard Light) as shown in Table 1. This test procedure detailed in the BS1377: Part 4: 1990. The method to carry out this test is not too difficult. For British standard light test, about 2500 g of oven dry soil that passed 2 mm sieve was obtained. The water is added into the soil starting with 5% of water and followed with 10%, 15% and so on until the weight of the compacted soil is reduced. Then the soil mixture is compacted into the mould in three layers by using 2.5 kg of hammer with 27 blows for each layer. The mould is weight and is recorded. The optimum moisture content is reached when the weight of soil and mould is reduced.

Table 1: Comparison of compaction test procedure (Source: [20])

Test Procedure	Rammer (kg)	Falling Height (m)	No. of Blow	No. of Layer	Compaction Force (kNm/m)
RBSL	2.5	0.3048	15	3	336.6
BSL	2.5	0.3048	27	33	605.9

Meanwhile, for reduced British standard light test, the test procedure are same as British standard level test. At this stage of compaction, about 2500 g of soil mixed with different percentage of geopolymer (5%, 10%, 15% and 20%). Then the soil is compacted into the mould in three layers by using 2.5 kg weight of hammer with 15 number of blows for each layer. The result of optimum moisture content (OMC) and maximum dry density (MDD) have been analyzed.

E. Data Analysis

After all the basic and engineering properties test have been done, the results that were collected for all the test were analyzed. In this stage, the results were presented in graph form to see clearly the difference between two different compaction effort which are RBSL and BSL.

RESULTS AND DISCUSSION

This chapter will present the results from the experimental work that have been done. There are two types of test that have been carried out which are physical properties test and compaction proctor test. The physical properties tests that are conducted including Particle Size Distribution Test, Atterberg Limit Test, Specific Gravity Test and Linear Shrinkage Limit Test. It is important to know the characteristic and properties of natural laterite soil. This test were conducted in order to determine the suitability of the laterite soil to be developed as soil liner and to know the best compaction effort that can be applied in construction of soil liner. The results of physical properties of laterite soil are compiled in Table 2. However, the conditions of laterite soil vary from place to place due to several factors such as climate, chemical composition and so on. The plasticity index (*PI*) of laterite soil is 6.15% and specific gravity is 2.60. The requirements of good plastic index for soil liner are 7.0% to 10.0% [21]. The PI for this soil does not reach the requirement value in designing a soil liner. However, with the presence of additive such as geopolymer, it will help enhanced the physical properties of soil. Meanwhile, the specific gravity of this soil reach the requirement value which stated by [22]. The linear shrinkage value for natural laterite soil is 7.38%.

Table 2: Physical properties of laterite soil

Parameters	Results
Grain Size Analysis	% Gravel : 0.88% % Sand : 77.48% % Fine : 21.64%
Atterberg Consistency Limits	LL : 58.61% PL : 52.46% PI : 6.15%
Specific Gravity	Gs : 2.60
Linear Shrinkage	7.38%

On the other hand, compaction test is performed in order to know the optimum moisture content and maximum dry density of the soil. Optimum moisture content is important to be determined in order to know how much of water can be sustain by the soil sample. In order to get the best and effective results, five soil samples have been prepared in this research. For sample number 1, the percentage of geopolymer that had been used is 5%, followed by sample 2, 3 and 4 which are 10%, 15% and 20%. The required percentage of water is added into the soil sample. The amount of soil that is used is about 2500 g. The graph of dry density and optimum moisture content are shown in Figure 2, Figure 3, Figure 4 and Figure 5.

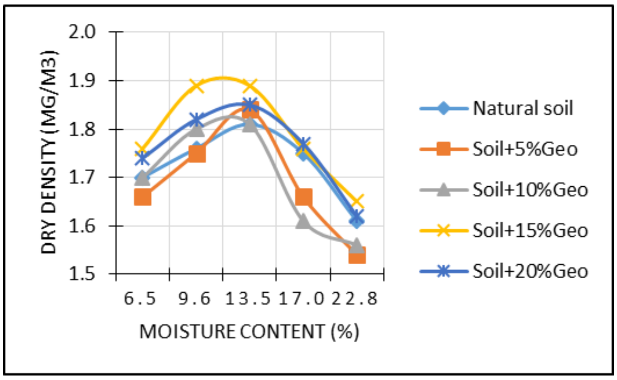

Figure 2: Dry density and moisture content of natural laterite soil and laterite soil with different percentage of geopolymer for British Standard Light test.

Figure 2 show the graph of dry density and moisture content of natural laterite soil and laterite soil mix with different perentage of geopolymer for British Standard Light test. From the results, it was observed that there exist a strong relationship between dry density, moisture content and geopolymer. The soil with 15% geopolymer give the higher value of dry density, which the maximum dry density for that mixture is 1.89 Mg/m^3 and 13.87% of moisture content. Meanwhile, for the soil mixture with 20% of geopolymer show less maximum dry density and optimum moisture content compare to soil mixture with 15% of geopolymer which 1.85 Mg/m^3 and 13.67% of moisture content. Laterite soil which have been added with geopolymer shows the increment in dry density and moisture content value compare to natural laterite soil. This is due to the action of the sodium hydroxide in the geopolymer which change the mineral in soil by alkaline attack.

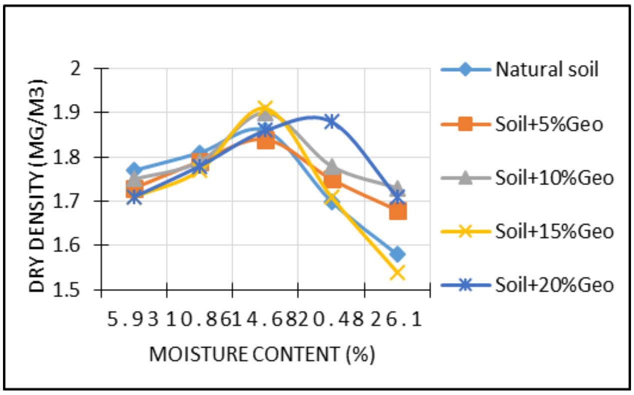

Figure 3: Dry density and moisture content of natural laterite soil and laterite soil mix with different percentage of geopolymer for Reduced British Standard Level test.

Furthermore, Figure 3 show the dry density and moisture content of natural laterite soil and laterite soil with different percentage of geopolymer for Reduced British Standard Light test. Based on the results, it is show that the value of dry density at first and second stage of compaction for natural laterite soil is high compared to soil mix with geopolymer. At the third stage of compaction, the soil that mix with 10% and 15% of geopolymer shows high value of dry density compared to other soil sample which are 1.84 Mg/m^3 and 1.90 Mg/m^3. Meanwhile, for soil mixture with 20% of geopolymer only shows the increment of dry density at stage four of compaction which are 1.88 Mg/m^3. It is happened because at third stage of compaction, the soil mixture still stiff and are difficult to compact. As the water content is increased the soil becomes more workable, improving compaction and resulting in higher dry densities at stage four. From this results, it can be conclude that the soil that have been mixed with 15% of geopolymer give the higher value of dry density which are 1.91 Mg/m^3 compared to natural laterite soil (1.81 Mg/m^3) and others soil mixture, 1.84 Mg/m^3 for 5% of geopolymer, 1.90 Mg/m^3 for 10% of geopolymer, and 1.88 Mg/m^3 for 20% of geopolymer.

The maximum dry density and optimum moisture content of soil with different percentage of geopolymer and different compaction effort are shown in Figure 4 and Figure 5. It is stated in previous research that when compaction effort is increased, the maximum dry density increases and the optimum moisture content of soil will be decreases. But, this fact is changed when geopolymer is mixed with the soil. From the results, it is proved that the Reduced British Standard Level test give higher value of maximum dry density, low optimum moisture content compared to British Standard Light Test for all percentage of geopolymer except for 5% of geopolymer which show the same value. Based on the value of maximum dry density for both types of compaction, it is show that the value of MDD of soil mixture achieve the requirement value in designing a soil liner system. Referred to previous research [23] and [24] stated that the requirement value of MDD in designing a soil liner must be more than 1.74 Mg/m^3 and 1.71 Mg/m^3. The results of this study show positive output which the value of MDD have achieved the requirement value in designing soil liner system. The results is expected because the characteristics of geopolymer itself which can easily react with water which results into a powerful compaction aid thus giving a higher density for the same compactive effort. It can be said the maximum dry density is increase with the increase in percentage of geopolymer at certain point and decrease back when it reach it optimum value.

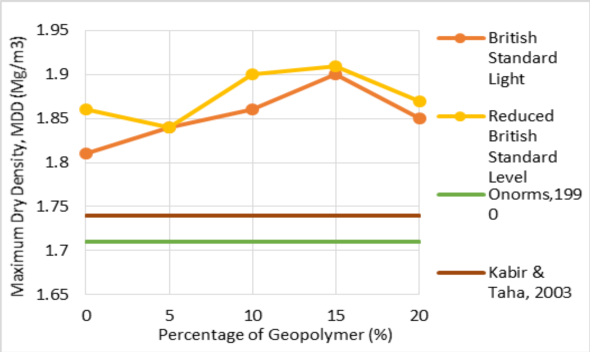

Figure 4: Comparison of Maximum Dry Density (MDD) value for Reduced British Standard Level test and British Standard Light test

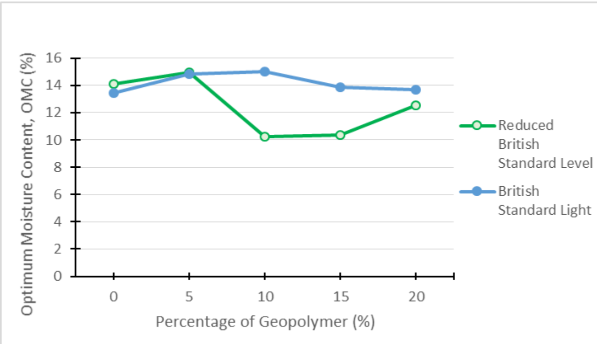

Figure 5: Comparison of Optimum Moisture Content (OMC) value for Reduced British Standard Level test and British Standard Light test

CONCLUSIONS

It is interesting to note that 15% of geopolymer used in this laboratory experiment generate a maximum dry density of 1.91 Mg/m^3 and optimum moisture content 10.38% under Reduced British Standard Level test for the laterite soil. The dry density of the specimens under 5%, 10% and 15% of geopolymer have increased with increase in percentage of geopolymer. It is due to the bonding created by alkaline solution and the subsequent isomorphous substitution of Aluminium (*Al*) has indeed increased the packing between the grains. For 20% of geopolymer, both of compaction parameter were decreased because both of compaction parameter already achieve its optimum value at 15% of geopolymer. For Reduced British Standard Level test, the maximum dry density was 1.91 Mg/m^3 at 15% of geopolymer, while the minimum was 1.84 Mg/m^3 under 5% of geopolymer. Meanwhile, for British Standard Light test, the maximum value of dry density are 1.89 Mg/m^3 for 15% of geopolymer and minimum value are 1.81 Mg/m^3 for natural laterite soil and 10% of geopolymer. The outcome of this study show that the Reduced British Standard Level test give better value of dry density and moisture content compare to British Standard Light test. These occurred because of the application of geopolymer which give a powerful compaction aid to the soil mixture and help increase the dry density of soil, increase the strength and thus automatically reduced the hydraulic conductivity of the soil. In a nutshell, the laterite soil mix with 15% of geopolymer give the best value of dry density and thus give the high strength and low hydraulic conductivity of soil with the less compaction effort. It can be apply in a construction of soil liner system because it fulfill the requirement in designing a soil liner system and with the application of geopolymer, it can directly reduce the cost of compaction.

ACKNOWLEDGMENT

The authors are thankful to University Technology MARA, Shah Alam for funding this paper and providing a place to carried out the experimental work. Special thanks to the laboratory staff for their valuable help in handling the laboratory equipment.

REFERENCES

[1] Stewart D.I., Cousens T.W., Studds P.G., and Tay Y.Y. (1999). "Design Parameters for Bentonite-Enhanced Sand as a Landfill Liner". Proceeding

[2] Benson C.H., Zhai H., and Wang X., (1994). "Estimating Hydraulic Conductivity of Compacted Clay Liner". J.ournal Geotech. Eng., 120(2), 366–387.

[3] Retrieved from http://www.pmstp.com/civil/geotextile/geotextile.html on 11 June 2015.

[4] Tiwari B., (2008). "Soil Mechanics Laboratory-Compaction Proctor Test". Civil and Environmental Enginering. California State University,Fullerton, 1-6.

[5] Daniel, D. E., & Wu, Y. K. (1993). Compacted clay liners and covers for arid sites. Journal of Geotechnical Engineering, 119(2), 223-237.

[6] Gidigasu M.D., and Kuma D.O.K., (1987). "Engineering Significance of Laterisation and Profile Development Processes". Proceeding 9th Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Lagos, 1, 3-20.

[7] Ola S.A., (1978). "Geotechnical Properties and Behaviors of Some Stabilizes Nigerian Lateritic Soils". Qwart J. Eng. Geol, 11, 145-160.

[8] Townsend F.C., (1985). "Geotechnical Characteristics of Residual Soils". Journal of the Geotechnical Engineering Division, ASCE 111(1), 77-94.

[9] Benerjee P.K., (1998). "Basic Research on Laterites in Tropical Countries". Quaternary International, 51-52, 69-72.

[10] Safiuddin L.O., Heris V., Wirman R.P., and Bijaksana S., (2011). "A Preliminary Study on the Magnetic Properties on Laterite Soils as Indicators of Pedogenic Processes". Latinmag Letters, 1(1), 1-15.

[11] Gidigasu, M.D. 1976. Laterite Soil Engineering: Pedogenesis and Engineering Principles. Elsevier, Amsterdam, the Netherlands.

[12] Douglas C. C., John H. P., Douglas J. R., (1989). "Applications of Geopolymer Technology To Waste Stabilization". 161-165.

[13] Cristelo N., Glendinning S., Fernandes L. and Pinto A. T., (2012). "Effect of Calcium Content on Soil Stabilisation with Alkaline Activation". Construction and Building Materials, 36, 727-7735.

[14] Torgal F. P., Adollahnejad Z., Camoes A. S., Jamshidi M. and Ding Y., (2012). "Durability of Alkali-Activated Binders: A Clear Advantage over Portland Cement or an Unproven Issue". Construction and Building Material, 30, 400-405.

[15] Nikolic I., Radomir Z., Velimir R., Dragoljub B., and Milena T., (2012). "Geopolymerization of Fly Ash as a Possible Solution for Stabilization Of Used Sand Blasting Grit". Scientific Paper, 243-246.

[16] Ansary M.A., Noor M.A., Islam M., (2006). "Effect of Fly Ash Stabilization on Geotechnical Properties of Chittagong Coastal Soil". Geotechnical Symposium in Roma, 443-454.

[17] ASTM C618 - 08 "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete". ASTM International. Retrieved 2014-03-20.

[18] Alshaaer, M.,(2000). " Stabilization Of Kaolinitic Soil From Jordan For Construction Purposes."M.sc Thesis, Vrije Universiteit Brussels, Belgium.

[19] Olaniyan O.S., Olaoye R.A, Okeyinka O.M, and Olaniyan D.B., (2011). "Soil Stabilization Techniques Using Sodium Hydroxide Additives", International Journal of Civil & Environmental Engineering IJCEE-IJENS, 11(6), 9-22.

[20] Osinubi, K.J. and Nawaiwu, C.M.O. (2006). "Design of Compacted Lateritic Soil Liners and Covers". Journal of Geotechnical and Geoenvironmental Engineering. 132(2): 203-213.

[21] Eberemu, A. O., Amadi, A. A., & Edeh, J. E. (2013). Diffusion of municipal waste contaminants in compacted lateritic soil treated with bagasse ash.Environmental earth sciences, 70(2), 789-797.

[22] Badmus, B. S. (2010). Plasticity and compressibility characteristics of lateritic soil from Southwestern Nigeria. Journal of Natural Sciences Engineering and Technology, 9(1), 14-22..

[23] Taha, M. R., & Kabir, M. H. (2003, July). Sedimentary Residual soils as a hydraulic barrier in waste containment systems. In Second International Conference on Advances in Soft Soil Engineering Technology, Putrajaya, Malaysia (pp. 895-904).

[24] Amadi, A. N., Okunlola, I. A., Eze, C. J., Jimoh, M. O., & Unuevho, C. I. (2015). Geotechnical Assessment of Clay Deposits in Minna, North-Central Nigeria for Use as liners in Sanitary Landfill Design and Construction. American Journal of Environmental Protection, 3(3), 67-75.