Assessment of Granite-derived Residual Soil as Mineral Seal in Sanitary Landfills

IGE, Olusegun Omoniyi[1] and OGUNSANWO, Olufemi[2]

1,2. Department of Geology and Mineral Sciences, University of Ilorin,
P. M. B. 1515, Ilorin, Nigeria. Email: vickyige2002@yahoo.com

Abstract: This study investigates the geotechnical properties of granite - derived soil from southwestern Nigeria for its potential use as mineral seal in sanitary landfill. The required parameters for soils to be considered as mineral seal such as grain size distribution, Atterberg consistency limits, maximum dry density and coefficient of permeability were determined using the BSI 1377 1990 standard. Results obtained show that the hydraulic conductivity is lower than the suggested limit (1 x 10^{-7}cm/s) of the various waste regulatory agencies. In addition, it has adequate basic geotechnical properties and strength characteristics which suggest the potential suitability of the soil as mineral seal in containment facility for disposal of solid waste material. [Reseacher 2009; 1(6): 84-90]. (ISSN:1553-9865).

Keywords: Mineral seal, Hydraulic conductivity, Residual soil, Unconfined Shear Strength, Nigeria.

1.0 Introduction

Waste material in waste containment facilities are made isolated from the surrounding environment by providing mineral seals. The mineral seal is to control or restrict the migration of pollutant into the environment (Ogunsanwo, 1996). Commonly use mineral seals are composed of natural inorganic clays or clayey soils. The low hydraulic conductivity of the compacted clayey soils combined with their availability and relatively low cost make them potential materials to use as mineral seals in sanitary landfills for environmental protection. Since it is desirable for containment system to achieve its purpose at minimum cost; careful consideration should therefore be given to the choice of materials for the construction of the mineral seal. The environmental and health hazards associated with "unengineered" landfills are well known (Asiwaju-Bello and Akande, 2004; Onipede and Bolaji, 2004, and Fred and Anne, 2005). In the U.S.A, Lee and Jones (2005) asserted that 75% of unengineered landfills pollute adjacent water body with leachate. This is because deposited waste undergoes degradation through chemical reaction thereby contaminating usable surface and subsurface water supplies. In addition, the produced leachate forms complexes with the sesquioxides of lateritic soil (Orlov and Yeroschicheva, 1967) thereby weakening their in-situ geotechnical properties (Ogunsanwo and Mands, 1999).

Granite-derived residual soils, like other soils of basement complex origin, are widely distributed over the country. Its traditional geotechnical properties have been studied (Alao, 1983; Ogunsanwo, 1988, 1996). The potential use of the soil, if found suitable, will reduce cost of construction of sanitary landfills and encourage friendly environment. However, for soil usefulness as mineral seal, certain recommendations have been proposed by several previous investigators (e.g ÖNORM S 2074, 1990; Daniel, 1993; Bagchi; 1994, Benson *et al,* 1994, Benson and Trust, 1995 and Ogunsanwo, 1996). The list of some of the required geotechnical parameters with the recommendations was presented in Ige (2009). Also minimum unconfined pressure of 200kPa was recommended by Tay *et al* (2001), Daniel and Wu (1993).

This study aims at assessing the geotechnical properties of a granite-derived residual soil for potential usage as mineral seals in landfills. The typical tests that are generally used to investigate soils proposed as mineral seals in landfill such as the grain size distribution, Atterberg limits, compaction, unconfined compressive strength and hydraulic conductivity were conducted on sample of the compacted granite-derived residual soil. If on the basis of these tests, the soil proves to have properties desirable for a mineral seal material, then it should be considered as a potentially suitable material for the isolation of waste material in sanitary landfill.

2.0 Materials and Methods

The material used for this study was granite-derived residual soil. The soil was taken at 1.83m depth of gully erosion – exposed soil profile, 2.7km, along Oke-Oyi/Oloru road in Ilorin, Nigeria. The sample was collected into a plastic bag and transported to the soil laboratory of the Yaba college of Technology, Yaba, Lagos. The basic test such as specific gravity, particle size distribution and Atterberg limits of the soil were performed. All analyses were carried out in accordance to the BSI 1377 (1990) version. The data of the index properties were used to classify the soil following the

Unified Soil Classification System (USCS) classification.

3.0 Results and Discussion

Several limits have been proposed by various researchers with respect to the geotechnical properties of soil to be useful as mineral seal. Such limits are presented here along with the results obtained from this study.

3.1 Grain Size Distribution and Atterberg limits tests

The specific gravity of the granite residual soil is 2.60. The particle size analysis shows that the soil contains 70% clay, 81% fines,15% sand and 3% gravel(Fig. 1) Moreover, the results of Atterberg limits reveal the liquid limit (LL) is 68.4%, the plastic limit (PL) is 24.0% and the plasticity index (PI= LL- PL) is 44.4%. On the basic of these data, the granite residual soil is classified as CH (Inorganic clay with high plasticity) according to the USCS (Fig. 2). Inorganic clay with high plasticity (CH) is recommended for landfill liner (Oweis and Khera, 1998).

Hydraulic conductivity behaviour of mineral seal is greatly influenced by the particle size distribution because the relative proportions of large and small particle sizes affect the size of voids conducting flow (Kabir and Taha, 2006). Mineral seal soils should have at least 30% fines (Daniel 1993b; Benson *et al*; 1994) and 15% clay (Benson *et al,* 1994) to achieve hydraulic conductivity $\leq 1\times10^{-7}$ cm/s. Thus, the granite-derived residual soil can be used as mineral seal to achieve a hydraulic conductivity $\leq 1\times10^{-7}$ cm/s, as it possesses suitable amount of clay and fine fractions. Moreover, the soil contains adequate amount of sand, which may offer notable protection from volumetric shrinkage and impart adequate strength as well.

Liquid limit is an important index property since it is correlated with various engineering properties. Soils with high liquid limit generally have low hydraulic conductivity. Benson *et al* (1994) recommended that the liquid limit of mineral seal material be at least 20%. Most of the specifications for mineral seal proposed by various researchers or waste regulatory agencies do not generally prescribe any limit (maximum value) for their liquid limit. As long as it does not create any working problem, soils with high liquid limit are generally preferred because of their low hydraulic conductivity. Thus, the granite-derived residual soil with liquid limit of about 68% appears to be promising for use as mineral seal.

The plasticity index is one of the most important criteria for the selection of soils as mineral seal in sanitary landfill construction. It is the key property in achieving low hydraulic conductivity. Literatures suggest that the plasticity index must be more than 7% (Daniel 1993; Benson *et al*; 1994; Rowe *et al,* 1995). Thus, the granite-derived residual soil has suitable plasticity property (PI is about 44.4%) to minimize hydraulic conductivity.

The activity (PI/% clay fraction) of granite residual soil is 0.63. Thus, according to Skempton's classification it is inactive clay. Inactive clayey soils are the most desirable materials for compacted soil mineral seal (Rowe *et al,* 1995). In order to achieve a hydraulic conductivity $\leq 1\times10^{-7}$ cm/s for the soil mineral seal, soil with an activity of > 0.3 has been specified (Benson *et al,* 1994, Rowe *et al,* 1995). An activity is an index of the surface activity of the clay fraction. Soils with higher activity are likely to consist of smaller particles having larger specific surface area and thicker electrical double layers (Taha and Kabir, 2006). Therefore, hydraulic conductivity should decrease with increasing activity.

Thus, the comparison between the index properties of granite-derived residual soil and the recommendations of various researchers for a good mineral seal material shows that the investigated granite residual soil has suitable properties to be use as mineral seal.

3.2 Compaction Properties.

The compaction curves (at two different energies of compaction) for the granite-derived residual soil are shown in Fig 3. The compaction curves clearly illustrate that the dry density is a function of compaction water content and compactive effort. For each compactive effort, at the dry side of optimum water content, the dry density increases with the increasing water content. This is due to the development of large water film around the particles, which tends to lubricate the particles and makes them easier to be moved about and reoriented into a denser configuration (Holtz and Kovacs, 1981). Whereas, at the wet side of optimum water content, water starts to replace soil particles in the compaction mould and since the unit weight of water is much less than the unit weight of soil, the dry density decreases with the increasing water content.

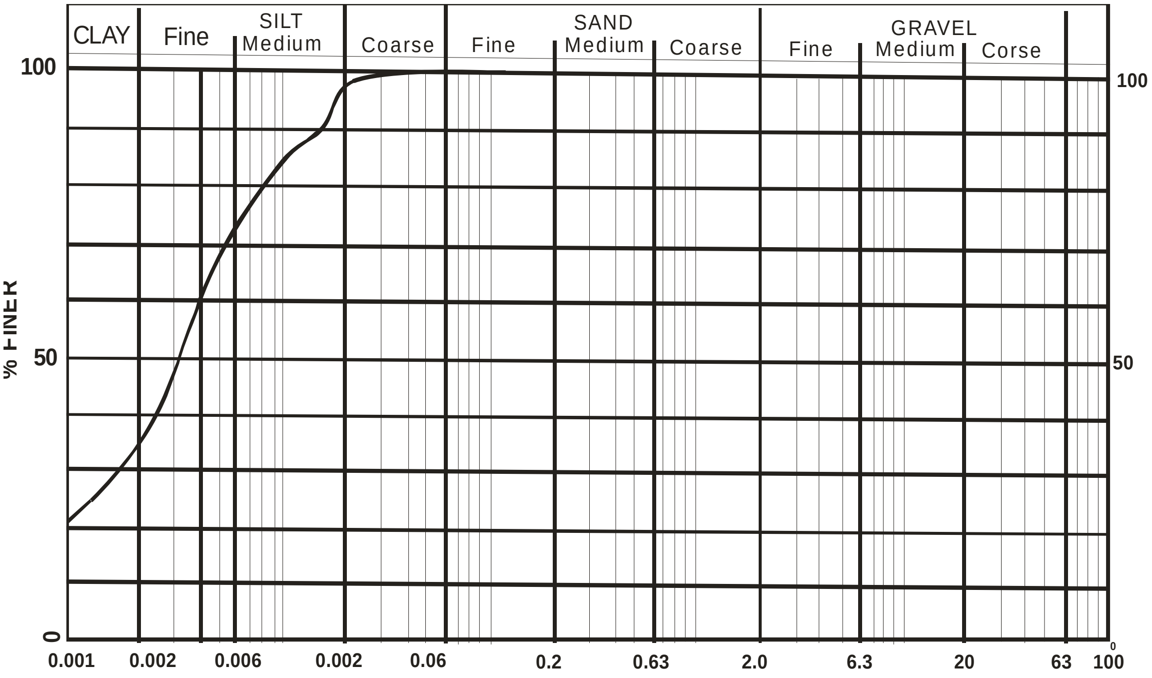


Figure. 1: The Plot of the Soil Sample on the Grain Size Distribution curve

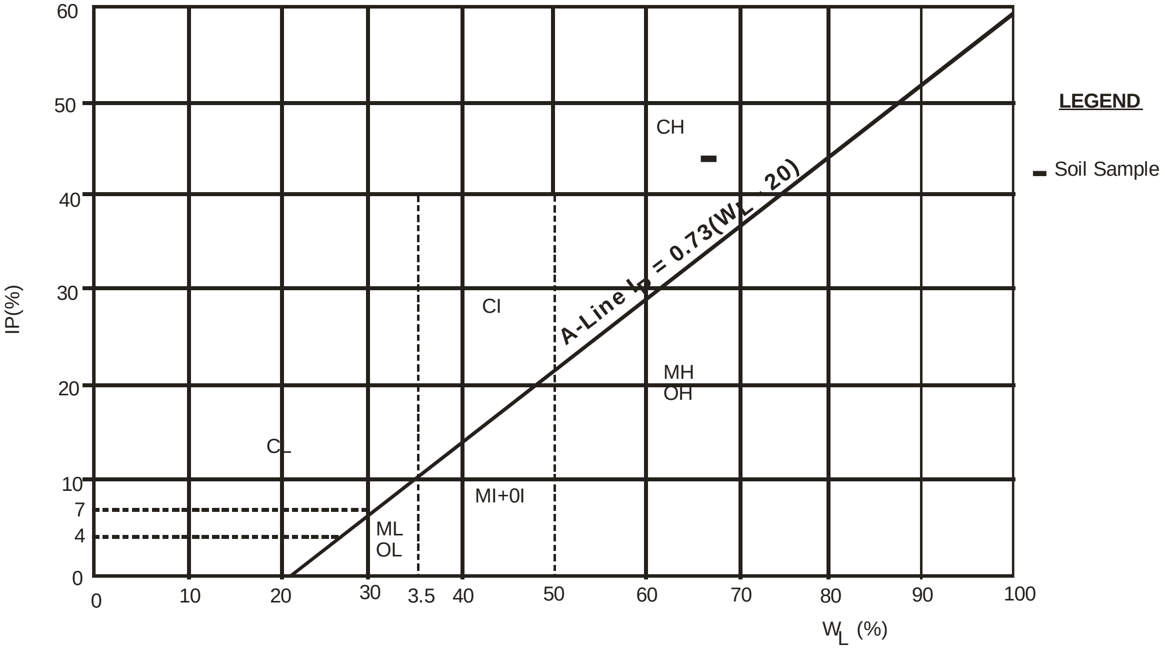


Figure 2 : Plot of the Soil sample on the Casagrande's Plasticity Chart.

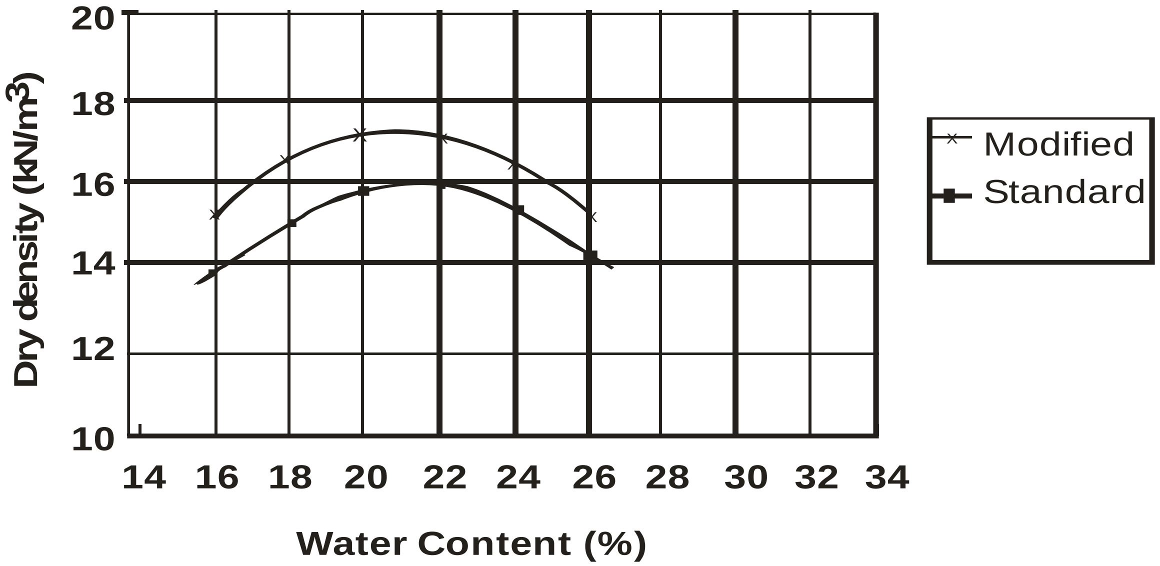


Figure 3. The Dry density versus Water content

The peaks of the curves (Fig. 3) represent the maximum dry density and corresponding optimum water content for a given compactive effort. The maximum dry density and the optimum water content obtained from these tests are given in Table 1. An increase in compactive effort increases the maximum dry density but decreases the optimum water content. This is because higher compactive effort yields more parallel orientation of the clay particles, the particles become closer and a higher unit weight of compaction results (Das, 1998). Hence, high compaction energy is preferred.

Table 1. Maximum Dry Density and corresponding Optimum Water Content.

Compactive Efforts	Optimum Water Content (w_{opt}%)	Max.Dry Density, γ(KN/m^3)
Modified Proctor	21.00	17.30
Standard Proctor	21.80	16.11

3.3 Hydraulic Conductivity

The relationship between hydraulic conductivity, water content and compactive effort is shown in Fig. 4. The hydraulic conductivity decreases with the increasing compactive effort because increasing compactive effort decreases the frequency of large pores and can eliminate the large pore mode (Acar and Oliveri, 1989). The reduction in pore size yields lower hydraulic conductivity. Figure 4 also show that the hydraulic conductivity of the soil changes with the change of compaction water content. Soils compacted at dry of optimum water content tend to have relatively high hydraulic conductivity whereas soils compacted at wet of optimum water content tend to have lower hydraulic conductivity. Increasing water content generally results in an increased ability to breakdown clay aggregate and to eliminate inter - aggregate pores (Mitchell *et al.*, 1965; Garcia-Bengochea *et al.*, 1979 Benson and Daniel, 1990). Moreover, increasing water content results in reorientation of clay particles and reduction in the size of inter- particle pores (Lambe, 1954; Acar and Oliveri, 1989 and Benson and Trust, 1995). Mineral seals should have a hydraulic conductivity of at least 1×10^{-7} cm/s. Figure 4 shows that the two different compaction efforts caused hydraulic conductivity less than 1×10^{-7} cm/s. The minimum hydraulic conductivity and corresponding water content at various compactive efforts is presented in Table.2.

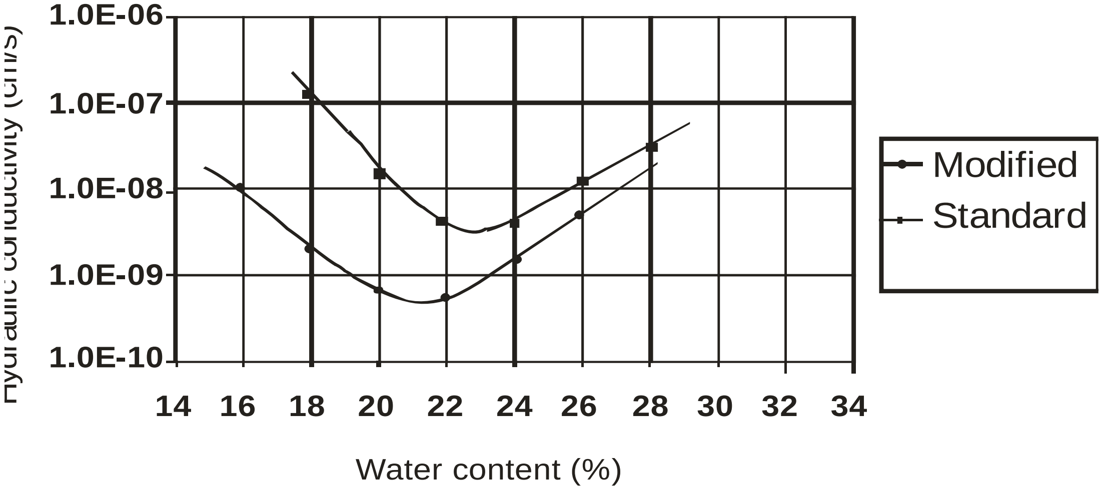


Figure 4: Hydraulic conductivity versus compaction water content

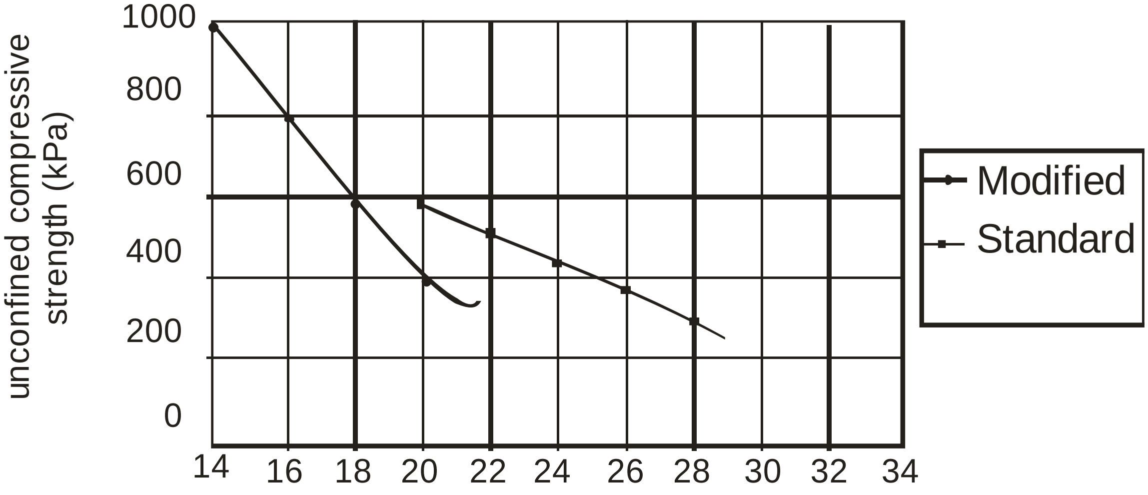
Table 2: Minimum Hydraulic Conductivity and Corresponding Water Content at various Compactive Efforts.

Compactive Efforts	Minimum hydraulic conductivity (cm/s)	Water Content (%) at Minimum Hydraulic Conductivity	Optimum Water Content (%)
Modified Proctor	3.2×10^{-9}	21.7	21.00
Standard Proctor	2.8×10^{-8}	22.5	21.80

3.4 Unconfined Compressive Strength.

The result of unconfined compression test against compaction water content is shown in Figure 5. The strength of compacted soil decreases with increase of compaction water content. Since increase in water content also increases the electrolyte concentration is reduced, leading to an increase in diffused double layer. Compactive effort also has a great influence on soil strength. For instance, at low compaction water content, unconfined compressive stress increases with increasing compactive effort. But at higher water content no clear trend is noticed.

Mineral seal in waste containment system is supposed to sustain certain amount of static load exerted by the overlying waste materials. In this regard, the mineral seal material must have adequate strength for stability. The bearing stress act on the mineral seal system depends on the height of landfill and unit weight of waste. Thus, the minimum required strength of soil used for compacted soil mineral seal is not specified but Daniel and Wu (1993) recommended that soils should have minimum unconfined compression strength of 200KPa. Test result shows (Fig.5) that the soil possesses higher strength than the recommended minimum strength of 200KPa for all the two compactive efforts.



Water content (%)

Figure 5: Unconfined compression strength versus compaction water content

4.0 CONCLUSIONS

The following conclusions can be drawn form the investigation of granite-derived residual soil:

The residual soil is inorganic clay with high plasticity. Generally, this type of soil possesses desirable characteristics to minimize hydraulic conductivity, and is frequently used for the construction of compacted soil mineral seals. The index properties (liquid limit, plastic limit, % clay content, % fines, activity etc.) of the soil satisfy the basic requirements as a mineral seal. It is inactive clayey soil. Thus, the soil will be less affected by waste leachate. The soil has hydraulic conductivity of less than 1×10^{-7} cm/s, when it is compacted with both modified and standard Proctor compaction efforts.

Moreso, the soil has average strength higher than 200kPa

Thus, it is concluded that the granite-derived residual soil can be used as a suitable mineral seal material in sanitary landfills. Its potential use as isolation mineral seal will enhance the waste management programs in Nigeria since granite-derived soils are locally readily available

Although the soil meets all the basic requirements as a good mineral seal material, it may pose little difficulties during filed application due to its high plasticity. Therefore, during construction, great attention should be focused on soil preparation. The soil should be properly blended and homogenized to achieve a mixture of relatively small clods.

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Correspondence to*:*
Olusegun Omoniyi IGE
Department of Geology and Mineral Sciences,
University of Ilorin, P. M. B. 1515, Ilorin, Nigria.
Telephone: +234-803-676-2252
Email: vickyige2002@yahoo.com

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