

Assessment of Geotechnical Properties of Migmatite-Derived Residual Lateritic Soil from Ado-Ekiti South Western Nigeria as Barrier in Sanitary Landfill

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ABSTRACT: Assessment of geotechnical properties of migmatite-derived residual lateritic soil from Ado-Ekiti Southwestern Nigeria was carried out to determine its suitability or otherwise as barrier in sanitary landfill.

Disturbed and undisturbed soil samples were collected from each of the four trial pits established at different depths within the lateritic zone. The disturbed samples were subjected to specific gravity test, grain size distribution analysis, consistency limits, and compaction tests while permeability test was carried out on undisturbed sample.

The soil samples taken from different depths within the lateritic zone in the four pits are generally well graded sandy clayey silt. The investigation also revealed that the soils are of medium to low plasticity and hence low compressibility. The maximum dry density obtained for all the samples range from 1610 kg/m³ to 1720kg/m³ while the optimum moisture content (OMC) values of the studied soil range from 16.5% to 23.5%. The coefficient of permeability obtained for the samples range from 1.79×10^{-4} to 1.80×10^{-3} . The coefficient of permeability obtained for samples taken from varying depths is significantly higher than the maximum value of 10^{-6} mm/s recommended for the soil that should form the base of landfills.

It is therefore recommended that in-situ compaction and lining be done if the soils at the location will be used as barrier in landfill. This will significantly prevent lateral and vertical movement of liquid phase of the wastes.

KEYWORDS: Geotechnical Assessment, Lateritic soil, Landfill, Permeability, Compaction

I. INTRODUCTION

Compacted soils are widely used as barrier in sanitary landfill to isolate hazardous and other waste materials from environment and groundwater. The effectiveness of compacted soils is controlled or enhanced by its hydraulic conductivity and permeability. Waste material in waste containment facilities are made isolated from the surrounding environment by providing barriers. The barrier is to control or restrict the migration of leachates into the groundwater and environment. Commonly used barriers are composed of natural inorganic clays or clay 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 barriers 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 barrier. Migmatite-derived residual soils, like other soils of basement complex origin, are widely distributed over the country. Its geotechnical properties have been studied. The potential use of the soil will reduce cost of construction of sanitary landfills and encourage friendly environment.

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The city of Ado-Ekiti falls within the Southwestern Nigeria. It is also the capital city of Ado-Ekiti, Nigeria. It has a population estimate of 409,060 people [1] which are responsible for the generation of high volume of wastes often deposited in open spaces, river banks, road side etc. thereby polluting the environment and groundwater.

With due consideration of the implication of the hazards posed by improper disposal of wastes on human beings and animals in Ado-Ekiti, geotechnical assessment of a location in Ilokun, Ado-Ekiti was carried out. The investigation was meant to generate data and information needed to design an acceptable sanitary landfill. The research was also meant to establish baseline conditions for the site with the determination of permeability coefficients of the soils in the area so as not to contaminate the groundwater.

Materials to be used in the construction of sanitary landfill barriers must have a sufficiently low hydraulic conductivity, low permeability, adequate interface strength, chemical compatibility and workability. It may be impossible to find soils readily available that satisfy all of these essential properties. USEPA allows the use of amended soils as sanitary landfill liner material [2].

II. RELATED WORK

Benson and Trast [3] conducted hydraulic conductivity tests on thirteen compacted clays commonly use as liners at landfills in the United States. They observed that for all the soils, zones exist in the compaction plane (moisture content-density curve) where the hydraulic conductivity is similar. Lower hydraulic conductivities were also obtained from soils that are more plastic and have higher quantity of fines material (clay+silt). They concluded therefore, that the degree of hydraulic permeability is a function of the amount fines that is present in soils.

Frempong [4] carried out an Engineering geological assessment of a proposed waste disposal site in the coastal southwestern Ghana. He explored the subsurface soil distribution and ground water condition through test pits. Geotechnical analysis was conducted on soils recovered from the test pits. From the results obtained, he classified some of the soils as inorganic silts of intermediate to high plasticity (MI-MH) while others were classified as inorganic clay of low plasticity (CL). The Liquid Limits range between 31-57%, Plastic Limits range between 14-43%, Plasticity Index range between 13-35%, percentage of fines (clay and silt) range between 70-91%, percentage of gravel range between 0-11% while sand range between 9-20%. The shear strength (C_u) of the soils also ranges from 20.6kN/mm/s. All the values obtained were below the specified maximum recommendations of various investigators and sanitary landfill regulatory agencies.

Adeyemi and Oyediran[5] carried out an engineering geological evaluation of a proposed landfill site at Aba-Kulodi, some 8km along Ibadan-Ife highway. Although the electrical resistivity survey conducted did not reveal the presence of fractures, and the grading and plasticity characteristics of the soils met the standard specifications for landfill seals, the permeability of some samples of the soil were higher than the maximum specified value of 1×10^{-6} mm/sec [6]. They pointed out that there is the need to line the base after compaction if the site is to be used as sanitary landfill.

Taha and Kabir [7] assessed the physical properties of a granite derived residual soil from Malaysia as barrier in landfill. The basic geotechnical properties of the soil were analyzed. Their results showed that the specific gravity is 2.63, Liquid limits (LL) is 68%, Index of plasticity (PI) is 33%. Other analyses included the moisture content density relationship, soil strength tests and the co-efficient of permeability from the results obtained. They concluded that the residual soil from granite rock can be suitably useful as isolation barrier in landfill.

Ige [8] investigated five soils from southwestern Nigeria for their suitability as mineral seals in sanitary landfills. He obtained specific gravity values ranging from 2.60 - 2.73, percentages of fine component ranged from 54% - 82%, liquid limit ranged from 40.6% - 68.0% and indices of plasticity from 18.6% - 44.0%. The maximum dry density at standard and modified Proctor energies range from between 1.74t/m³- 1.96t/m³ and 1.91t/m³-1.12t/m³ respectively and a highest coefficient of permeability value of 1.83×10^{-9} m/s was obtained for the soils. He therefore concluded that the soils are good as mineral seals.

Ige [9] investigated the geotechnical properties of a migmatite - derived soil from southwestern Nigeria for its potential use as barrier in sanitary landfill. The required parameters for soils to be considered as barrier such as grain size distribution, Atterberg consistency limits, maximum dry density (MDD) and the coefficient of permeability were determined. Results obtained showed that the hydraulic conductivity is lower than the suggested limit (1×10^{-7} cm/s) of the various waste regulatory agencies. In addition, it has adequate basic geotechnical properties, strength and the

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shrinkage potential upon drying. These properties suggest the potential suitability of the soil as a barrier in containment facility for disposal of waste material.

Ige [10] investigated the geologic and geotechnical characteristics of a selected functional open landfill with a view of converting to a modern sanitary landfill. Required parameters for soils to be considered usable in such containment facility were evaluated. Results showed that the site is locally underlain by unfractured migmatite which is fresh and competent enough to provide sufficient supports for modern sanitary landfill. Geotechnically, lateritic soil samples over the site have largest grain size of 10mm, average clay portion of 33%, sand of 51% and gravel size of 3.75%. The samples have low to medium plasticity and clay activity of 0.39. The average Maximum Dry Density and coefficient of permeability are 1.80g/cm^3 and $1 \times 10^{-8}\text{m/s}$ at lighter energy of compaction. This study showed that conversion of the existing open landfill to modern one is possible since all geologic and geotechnical criteria are suitably present.

Ogunsanwo and Ige [11] investigated the geotechnical properties of two soils derived over basement complex rocks from southwestern Nigeria for their use as barriers in sanitary landfill. Required parameters for soils to be considered as barriers were determined in accordance with the British Standard Institute. Results showed that the soils satisfied basic geotechnical properties and are classified as non-expansive clay of low to medium plasticity. The Maximum Dry Density values are low at standard Proctor energy of compaction but improved under modified condition. One of the samples has coefficient of permeability value that fall within several recommendations, even at low energy of compaction. The second sample will require higher energy of compaction to achieve low permeability value. All values generally compare favourably with those suggested by regulatory agencies and several investigators. Thus, they are suitable for use as barriers in sanitary landfills.

Adeoye *et al.* [12] investigated the geotechnical properties of five soils from southwestern Nigeria for their use as liners in sanitary landfill for disposal of solid waste. The required parameters for soils to be considered as liners were determined in accordance with the British Standard Institute. Results obtained showed that the percentage of fines range from 42% to 82% and index of plasticity values range from 25.0% to 32.6%. Clay activity varies between 0.47 and 0.88. Thus, the soils are classified as non-expansive clay of low to medium plasticity. The maximum dry density values at standard Proctor energy of compaction range from 1.46g/cm^3 to 1.96g/cm^3 while those obtained at modified Proctor energy range from 1.57g/cm^3 to 2.09g/cm^3 . The highest coefficient of permeability value obtained for all soils investigated is $2.99 \times 10^{-9}\text{m/s}$. All values compare favourably with those suggested by regulatory agencies. Consequently, they are suitable for use as liners in sanitary landfills.

Bozbey and Guler [13] investigated the feasibility of using a silty soil excavated in highway construction as landfill liner material. The tests were conducted both at laboratory and in situ scales, and the soil was tested in pure and lime treated forms. Different levels of compaction energy were used. For the field study, a test pad was constructed and in situ hydraulic conductivity experiments were conducted by sealed double ring infiltrometers (SDRI). Laboratory testing revealed that while lime treatment improved the shear strength, it resulted in higher hydraulic conductivity values compared to pure soil. It was observed that leachate permeation did not change the hydraulic conductivity of the pure and lime treated samples. Laboratory hydraulic conductivities were on the order of 10^{-9}m/s and met the $1.0\text{E}-08\text{m/s}$ criterion in the Turkish regulations, which is one order of magnitude higher than the value allowed in most developed countries. SDRI testing, which lasted for 6 months, indicated that lime treatment increased the hydraulic conductivity of pure soil significantly in the field scale tests. In situ hydraulic conductivities were on the order of $1\text{E}-08$ and $1\text{E}-07\text{m/s}$, and exceeded the allowable value in the Turkish regulations. Undisturbed samples collected from the test pad were not representative of field hydraulic conductivities. Contrary to laboratory findings, higher compaction efforts did not result in lower hydraulic conductivities in field scales. The study verified the importance of in situ hydraulic conductivity testing in compacted liners.

III. STUDY AREA

The study area is in the humid tropical part of southwestern Nigeria which is underlain by migmatite complex. The area which is located at the northern part of Ado-Ekiti is within Ado Local Government area of Ekiti State. It is located at Ilokun, on the outskirts of Ado-Ekiti adjacent Ado-Iworoko road. The study area lies between Longitudes $5^{\circ}00'$ and $5^{\circ}20'$ east of the Greenwich meridian and latitude $7^{\circ}00'$ and $7^{\circ}45'$ north of the Equator (Fig. 1) with elevation range of

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254m to 265m above the mean sea level. The study area falls within the Basement Complex of Southwestern Nigeria. The sampling location is generally accessible through network of roads, footpaths etc.

The choice of the area was based on the fact that it is fairly remote from the residential area, major highway and river. The area has a gentle slope. The sampling location is presently used as open dumping/burning site.

The drainage system over the areas of basement complex rocks is usually marked with the proliferation of many small river channels. The channels of these smaller streams are dry for many months, especially from November to May. In Ekiti State, there is no major river. However, the state serves as the watershed and source region for three major rivers that flow into the Atlantic Ocean. These are the Rivers Osun, Owena and Ogbese

The climate is of the Lowland Tropical Rain Forest type with distinct wet and dry seasons. The dry season comes up between November and April while the wet season prevails between May and October. In the south, the mean monthly temperature is about 28°C while the mean relative humidity is over seventy five per cent. However, in the northern part of the state, the mean monthly temperature may be over 30°C.

The mean monthly relative humidity here is about 65 per cent. The mean annual total rainfall in the south is about 1800mm while that of the northern part is slightly over 1600mm.

As indicated under climate, the expected climax vegetation is the evergreen high forest composed of many varieties of hardwood timber, such as a procera Terminalia superba, Lophir, Khivorensis, Melicia excelsa and Antiaris africana. This natural vegetation is hardly present now but relics are observable, especially in the southern half of the state where some forest reserves are established by the government.

IV. GEOLOGY

The study area, Ado-Ekiti, forms part of the area underlain by the Precambrian Basement Complex rocks of southwestern Nigeria [14,15] which comprises igneous and metamorphic rock units such as gneisses, masses, including older granite ridges and pegmatites. The area is underlain dominantly by migmatite-gneiss. It has a coarse grained texture with occurrences of quartzofeldspathic veins in them. Essentially, the metamorphic rocks and igneous intrusions such as vein dykes and pegmatites underlie the area. These rocks occur either directly exposed or covered by shallow mantle of superficial deposits. Though the assemblages have been variedly classified, they may be broadly subdivided into the ancient migmatite-gneiss complex, the schist belts and Pan-African (ca. 0.6ga) intrusive series or the older granites plus minor rocks. Radiometric ages obtained from ancient migmatite-gneisses are notably between ca. 2.8 and 2.0 ga (23) older dates (> 3.0ga) have more recently been derived from some.

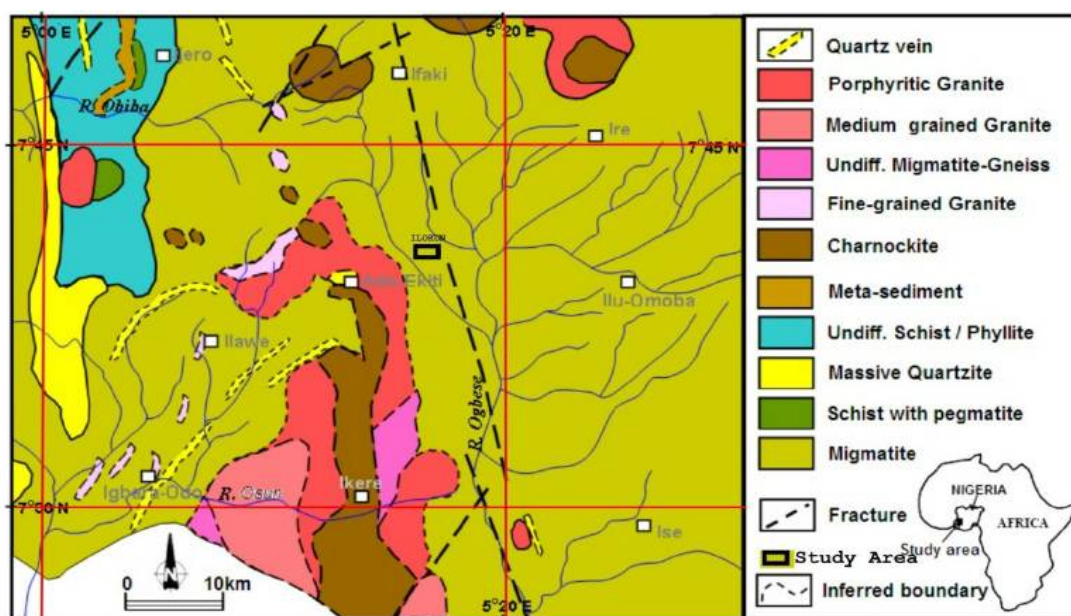


Figure 1: Geological Map of the Area around Ado-Ekiti, Showing the Study Area
(Adapted from Akure Sheet 56 Geological Map)

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V. METHODOLOGY

The research work involved geotechnical method of investigation .This involves collection of soil samples (disturbed and undisturbed) at different depths in a trial pit which is the cheapest method of exploration to shallow depth which enables a clear picture to be obtained of the stratification of soils and the presence of any lenses or pockets of weaker materials. For the purpose of this work geotechnical sampling involved the establishment of four trial pits. Both disturbed and undisturbed samples were obtained at different depth within the lateritic zone. The variation in the depth of soil sample was necessary to know the geotechnical properties of the laterite zone which may be useful as mineral seals in the construction of sanitary landfill. The disturbed samples collected in polythene bags were obtained using digger and shovel. The undisturbed samples were obtained using cutters (100mm x150mm) with marshal rammer ramming it into place. The core cutter was sealed on both edges immediately with candle wax melted on the field to prevent loss of moisture.

The disturbed samples were subjected to specific gravity test, grain size distribution analysis, consistency limits, and compaction tests while permeability test was carried out on undisturbed sample at soil laboratory according to BS 1377 [16] standard. The results obtained were later compared the recommendation of several previous authors, researchers and regulatory agencies.

VI. RESULTS AND DISCUSSION

Geotechnical Properties of the Studied Soils

Several limits have been proposed by various researchers with respect to geotechnical properties of soils to be useful as barriers in sanitary landfills. These limits have been compared with the results of the studied parameters and presented below.

Specific Gravity

Specific gravity is the ratio of the mass of a given volume of material to the mass of an equal volume of water at a temperature of 4°C. The specific gravity of soil particles is an important engineering index property often employed in estimating the degree of laterization of lateritic soil [17, 18].

The specific gravity of the investigated soil ranges between 2.51 and 2.58 which is far better than 2.2 recommended by Onorm [19]. Alexander and Cady [20], gave values of 2.50 to 3.60 for specific gravity of lateritic soils. Thus, the specific gravity value of the derived soil samples fall within the stipulated range. Truncer and Lohnes [18] noted that the specific gravity of soil particles is a very good primary index property to characterize lateritic soils as it reflects their iron and sesquioxide content and the extent of laterization. High specific gravity values indicate a high degree of laterization.

Akroyd [21] had suggested the use of specific gravity in assessing the maturity of lateritic soils. The higher the specific gravity of lateritic soils and the degree of laterization, the stronger the soils would be.

Table 1: Result of Specific Gravity of the migmatite-gneiss-derived soil samples

Samples	KIKI 1		KIKI 2		KIKI 3		KIKI 4	
Specific Gravity	2.54	2.52	2.50	2.52	2.59	2.57	2.58	2.56
Average Specific Gravity	2.53		2.51		2.58		2.57	

Table 1 shows that there is a very close range in the values of the specific gravity of the grains of the studied soils since the soils are of the same genetic origin and in the similar weathering environment.

Grain Size Distribution

This test is important in estimation of relative proportion of various size grades in the samples. The physical and engineering properties of lateritic soils have been found to depend on their textural characteristics.

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A combination of grain size distribution characteristics of soil with plasticity enhances an easy classification of the soil. Although grading characteristics has little relevance in the characterization of fine-grained soil. Most of the engineering properties of coarse-grained soils are closely associated with predominant particles size.

The amount of fines in a soil which is percentage finer than 63 micrometers (clay and silt size) is an important parameter often employed in the classification and characterization of soils.

Table 2: Summary of the Grain Size distribution characteristics of the studied soils

SAMPLES	GRAVEL (%)	SAND (%)	AMOUNT OF FINES (%)
KIKI 1	6	48	46
KIKI 2	2	58	40
KIKI 3	7	41	52
KIKI 4	1	53	46

In all the soil samples taken from different depths of the trial pits, the amount of fines ranges from 40% to 52%. Table 2 shows that the soil sample in the third trial pit (KIKI 3) has amount of fines greater than 50%. The amount of fines for the samples taken from the first, second and fourth trial pit (KIKI 1, KIKI 2 and KIKI 4) are less than 50%. Daniel [22] recommends amount of fines not less than 20% for soil that will suitable for landfill seals. The studied soils are thus good for the base of a landfill.

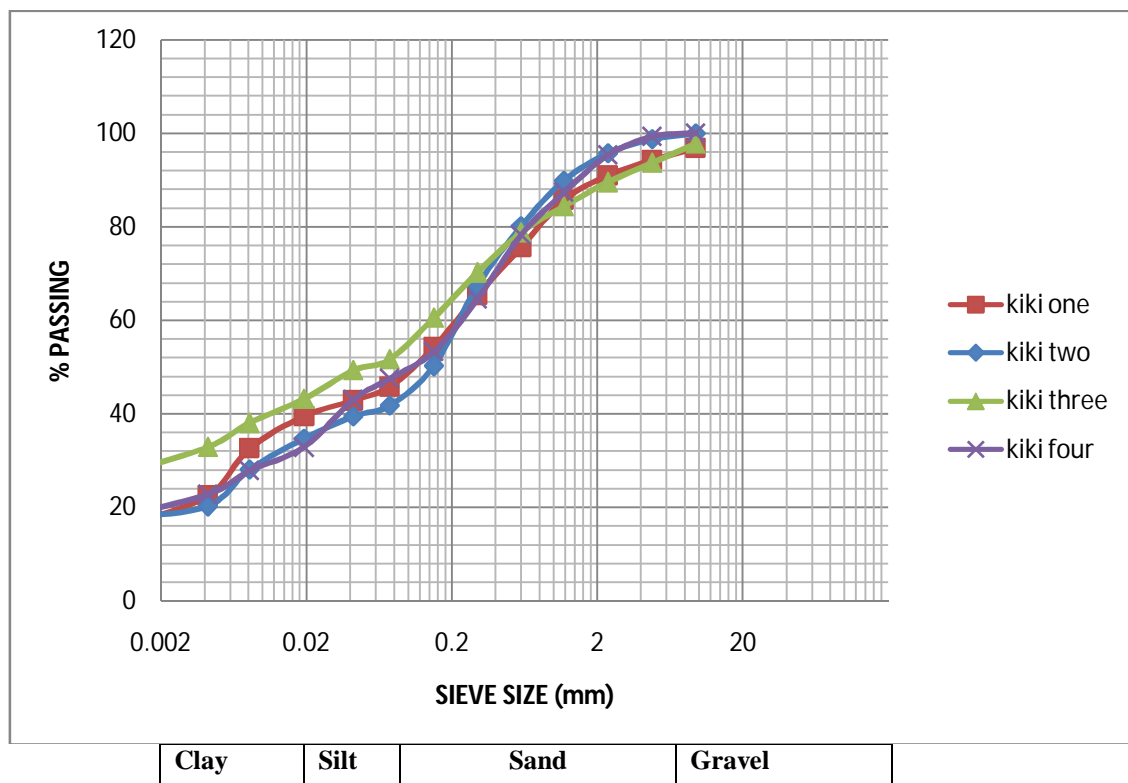


Figure 2: Grading curves of lateritic soil samples

The grading curves of the studies are presented in figure 2. The summary of the grain size distribution characteristics of the studied soils are shown in table 2 above.

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Consistency Limits

A consistency limit characteristic is an important factor in the selection of lateritic soils both as sub-grade and sub-base materials.

The plasticity of a soil is a measure of the affinity which a soil has for water. It is often expressed in terms of the plasticity index which is the numerical difference between the liquid limits and plastic limits. The mineralogical composition of the soil and the parent rock affects its plasticity significantly. For instance, alkali feldspar is transformed into kaolinite while biotite changes to the clay mineral vermiculite, both of which are highly hydrophilic. Casagrande [23] did indicate that the higher the value, the poorer would be the soil as an engineering soil. Materials with low plasticity do not compress appreciably under load nor do they shrink extensively when dried so that when once they have acquired firm consistency near plastic limit they are quite stable.

Table 3: Consistency limits (%) of the studied soils

Sample location	Liquid limit	Plastic limit	Plasticity index (%)	Plasticity type	Soil type
1	43.0	26.1	16.9	Medium	Inorganic
2	35.0	19.2	15.8	Medium	Inorganic
3	45.2	27.5	17.7	Medium	Inorganic
4	50.0	23.4	26.6	Medium	Inorganic

Table 3 summarizes the consistency limits of the studied soils. It also indicates that the four samples plot in the medium plasticity regime hence they are good engineering soils and can be used for the base of landfill. The liquid limits of all the samples range from 35.0% to 50.0%. The plasticity indices of all the samples range from 15.80% to 26.60%.

Kabir and Taha [24] reveals that soils with high liquid limit usually have low hydraulic conductivity thus the studied soils are expected to exhibit low hydraulic conductivity and therefore suitable for use as liner materials.

Benson *et al.*, [25] indicated that plasticity index must be greater than 7% for soils to be suitable for use as liner materials hence the studied soils are suitable to be used as barrier in sanitary landfill.

Compaction Test

The results of compaction tests carried out at different energies of compaction to obtain the soils maximum dry density (MDD) and the corresponding optimum moisture content (OMC) values are presented in Table 4. Benson and Trast [3] reported that the coefficient of permeability is sensitive to compactive effort and molding water content.

Table 4: Compaction Test Results

SAMPLE	KIKI 1	KIKI 2	KIKI 3	KIKI 4
OMC (%)	16.5	21.0	23.5	21.0
MDD (kg/m ³)	1720	1610	1650	1700

The soil maximum dry density (MDD) values for standard Proctor energy of compaction range between 1610kg/m³ to 1720 kg/m³ while the optimum moisture content (OMC) values of the studied soil range from 16.5% to 23.5%. These values are higher than 1450kg/m³ (standard Proctor) of maximum dry density (MDD) recommended by Taha and Kabir [7] for soils produced from basement complex rocks to be useful as barrier in sanitary landfills.

For any soil to be suitable for general filling, construction of sub-grade and sub-base courses of roads and base of landfill, the maximum dry density (MDD) must exceed 1700 kg/m³ (Nigerian General Standard Acceptable Limits FMW, 1997) [26]. Two samples, KIKI 1 and KIKI 4 meet this requirement and therefore suitable for base of sanitary landfill.

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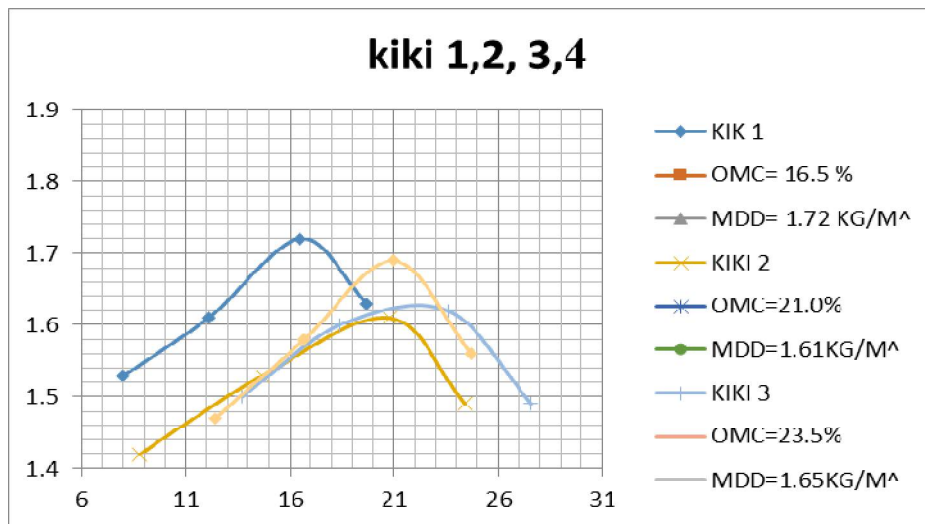


Figure 4: Graph showing the Optimum Moisture Content and Maximum Dry Density of the studied soils

Permeability Characteristics

The permeability of a soil is dependent on the soil texture and structure. It is a property of soil by virtue of which the soil mass allows fluid to flow through it. The coefficients of permeability, “k” of the soils determined in the laboratory range from 1.79×10^{-4} to 1.80×10^{-3} which is displayed in Table 5. The permeability characteristic of soil is very important in the determination of its suitability for construction particularly for use in landfills.

Lambe [27] in classifying soils based on permeability used a permeability of 10^{-4} mm/s as a borderline between pervious and impervious soils. According to Clayton and Huie [6] the permeability coefficient for the base of a landfill should not exceed 10^{-6} mm/s while all the samples do not meet the standard recommended. This is because the soil samples have permeability coefficients in excess of the recommended figures. It is therefore recommended that in-situ compaction and lining be done if the location is to be used as land fill site. This will prevent lateral and vertical movement of ground water and liquid phase of the wastes.

VII. CONCLUSION

Based on the geotechnical investigations carried out on both disturbed and undisturbed soil samples taken from four trial pits at identical depth and from the foregoing interpretation and discussion of the basic geotechnical properties of the studied soils, the following conclusions are drawn:

The residual lateritic soil samples are well graded and they exhibit low plasticity. The samples contain high amount of fine grained particles, especially silt-sized micaceous particles which have been derived from micas that constitute bulk of the minerals in parent rock. All the samples contain amount of fines significantly higher than the minimum values recommend for soils that should be used as barrier in landfill.

The plasticity indices of the samples are very low hence; they are good engineering soils and can be used for the base of a landfill.

The result of compaction characteristics of the studied soil revealed that they are suitable for general filling, construction of sub-grade and sub-base courses of roads and base of landfill.

The co-efficient of permeability obtained for the studied samples are significantly higher than the maximum value recommended for the soil that should form the base of landfills. However, the soil can be used as barrier in landfill if in-situ compaction and lining are done.

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