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Residual Soils Derived from Charnockite and Migmatite as Road Pavement Layer Materials

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Abstract

Suitable soils for road pavement layer construction are getting depleted. Highway Engineers are consistently in search of locally-available and suitable soils for road construction. This paper investigates the potential use of residual soils derived from charnockite and migmatite as road pavement layer materials. Natural moisture content, sieve and hydrometer analyses, specific gravity, Atterberg limits, compaction, California bearing ratio (CBR), and permeability characteristics of soil samples collected from six different locations in Ekiti State, Nigeria were determined. The soils derived from charnockite have their average unsoaked CBR, soaked CBR and permeability to be higher than those of the soils derived from migmatite by 64.7%, 73.5% and 1750.9%, respectively. Consequently, some of the soils derived from charnockitesatisfy the requirements by the Nigerian General Specification for use as subgrade and subbase materials, while those derived from migmatite generally have poor geotechnical properties. The soils derived from charnockite are recommended for use as pavement layer materials, while those derived from migmatite need to be stabilized before being used.

1. Introduction

During the planning of road, railroad and airfield construction, materials selection for earthwork plays a vital role toward the efficient execution of such construction and the functional operation of the resulting infrastructure. It is essential to identify and use suitable soil materials for earthworks. However, conventional sources of suitable soil materials for the earthwork of such construction are fast getting depleted [1, 2], if not already depleted. Where there are suitable materials, some are very far from proposed project sites, consequently adding transportation or haulage cost and thereby increasing the overall project cost. Highway Design Engineers favour the use of locally-available and suitable materials in order to minimize overall project costs of road pavement constructions. It is, however, necessary to investigate the engineering properties of locally-available soils in order to know how best to use them for road, railroad and airfield pavement construction. Consequently, this research work investigates the potential use of residual soils in selected areas of Ekiti State, Southwestern Nigeria, derived from charnockite and migmatite, as road pavement layer materials.

The study area is located in Ekiti State between latitudes 07°31′ and 07°49′ North and longitudes 05°07′ and 05°27′ East. It has a tropical climate with two distinct seasons, viz, rainy season (April – October) and dry season (November – March), and a dry spell in August. The average precipitation is about 1408 mm. This area is characterized by evergreen vegetation, where tall trees with thick under growths are common. The people in the study area are largely farmers. Human activities such as bush clearing, building and road constructions have changed the natural setting of this area.

Ekiti State lies within the Precambrian crystalline basement complex of Nigeria. Five major groups of rocks lies within this area. They are:

(i) the migmatite-gneiss complex, which comprises biotite hornblende gneisses, quartzites and quartz schist, and small lenses of calc-silicate rocks;
(ii) slightly migmatized to unmigmatizedporaschists and meta-igneous rocks, which consist of politic schists, quartzites, amphibolites, metaconglomerates marbles and calc-silicate rocks;
(iii) charnockitic rocks;

(iv) older granites, which comprises rocks varying in composition from granodiorite to true granites and potassicsyenite; and
(v) unmetamorphosed dolerite dykes, which is believed to be the youngest.

The relief of the study area is rugged with an average elevation of about 210 m above sea level. The drainage pattern is dendritic with the direction of river flow mostly southward. The typical weathering profile of the study area include: (i) topsoil (termite soil) (ii) laterite (gravelly soil layer) and (iii) clay zone (mottled zone). Some of the major rock types found in the study area include migmatite-gneiss, porphyritic granite and charnockite, forming hills in many places. The land areas surrounding the hills are usually flat to gentle-rolling. The study area is underlain mainly by the migmatite-gneiss complex, charnockitic and older granitic rocks. The migmatite-gneiss – quartzite complex is most widespread in the basement complex of southwestern Nigeria. It comprises of gneisses, calc-silicate rocks, biotite- hornblende schist and amphibolites.

Three locations within Ekiti State were selected for this study and they include:
(i) a plot beside Ayemi Garage at Ado-Ekiti, along Iworoko road;
(ii) beside Iworoko Grammar School; and
(iii) a roadside cut at Ayegbaju along Ikole Road.

2. Experimental

2.1 Collection of soil samples

Two sets of disturbed soil samples were taken from each of the three study sites (Figure 1). Samples taken from a pit on a plot beside Ayemi Garage at Ado-Ekiti were denoted by DK1 and DK2 and are derived from charnockitic rocks. Samples taken from a pit beside Iworoko Grammar School were denoted by WK1 and WK2 and are derived from migmatitic rocks while those taken from a road side cut at Ayegbaju were denoted by AG1 and AG2 and are derived from charnockitic rocks.

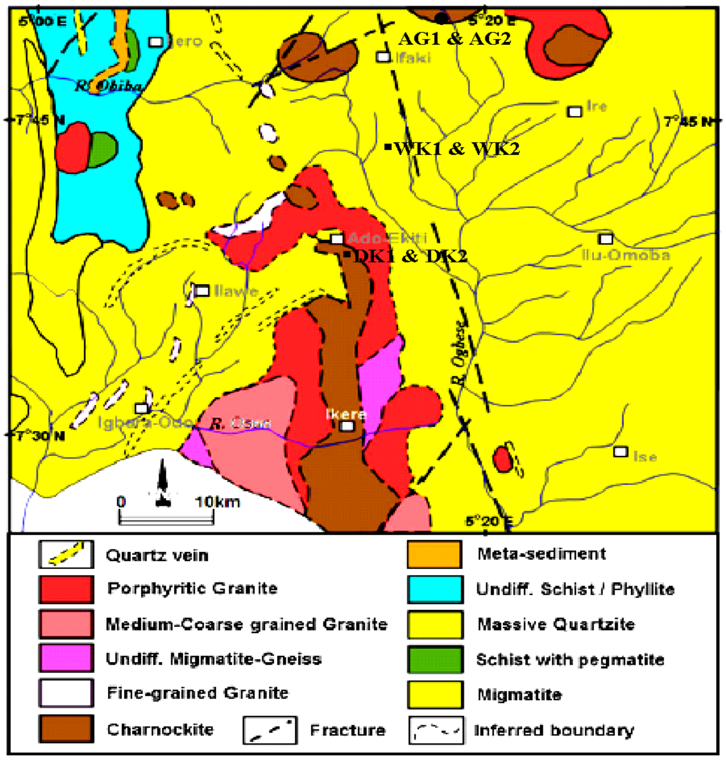


Figure 1: Geological map of the study area (After [4]).

The mineralogical and oxide composition of the rocks in the study area from which these soils were derived were reported by [3] and are graphically illustrated in Figures 2 and 3, respectively. Figure 2 shows that quartz, feldspar and hornblende are the predominant minerals in the charnockite of the study area, occupying 88% (by volume) of the minerals of the rock. Quartz, feldspar, biotite and hornblende also occupy 88% (by volume) of the minerals of the migmatite. Silica (SiO_2) and sesquioxides of aluminum and iron (Al_2O_3 and Fe_2O_3) are the predominant oxides in the typical rocks from which the soil samples in the study sites were derived. The rocks that were broken down to form the DK, WK and AG samples have these three oxides constituting 81.49%, 87.25% and 82.39%, respectively (Figure 3).The disturbed soil samples collected from each of the three study locations were taken at depths ranging from 1–2 m below the existing ground level. Soil samples for natural moisture content determination were collected from the sites in watertight (polythene) bags. The samples were air-dried for 24 hours in the laboratory prior to testing.

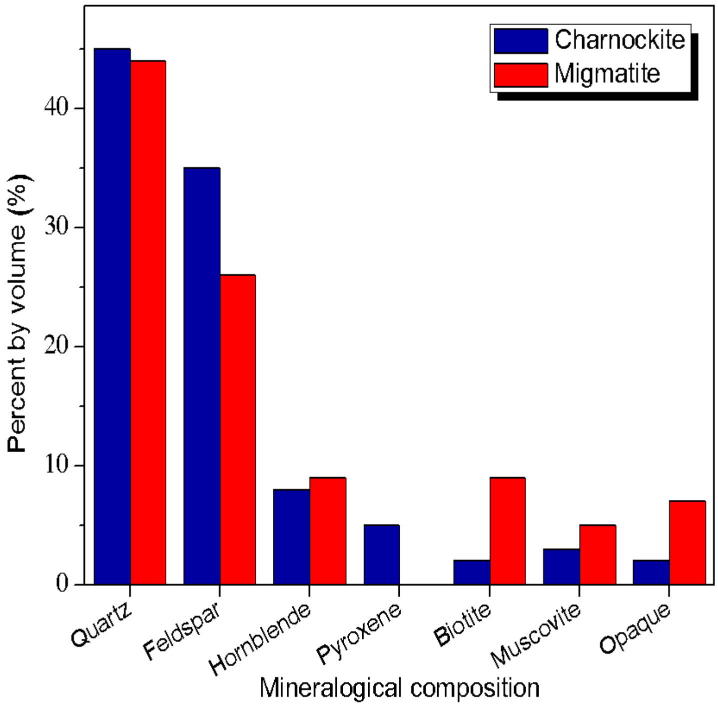


Figure 2: Typical mineralogical composition of rocks from which the soils were derived.

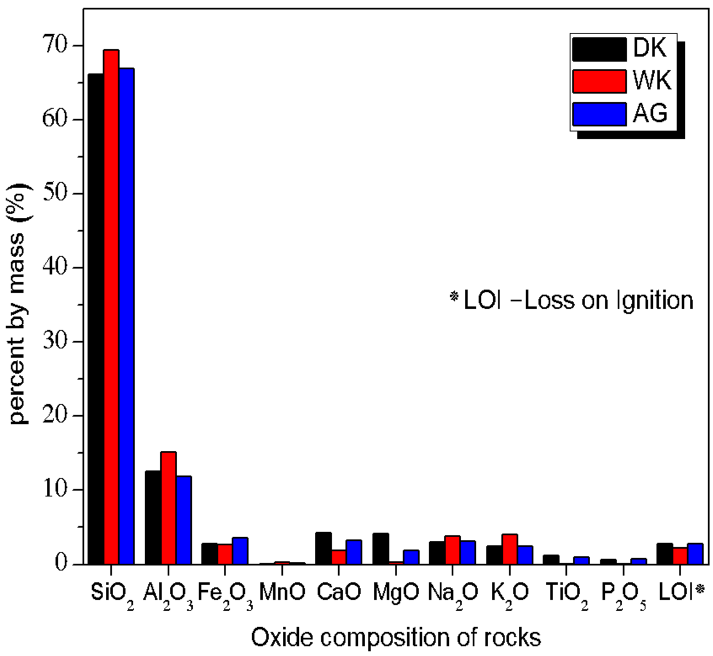


Figure 3: Typical oxide composition of rocks from which the soils were derived

2.2 Determination of testing parameters

The natural moisture content of the soil samples were determined in the laboratory using the oven-drying method while their particle size distribution curves were plotted from the results of sieve and hydrometer analyses. For the samples taken from each of the sites, specific gravity, Atterberg limits, compaction, California bearing ratio (CBR) and permeability tests were performed in triplicate and their mean values are presented.

Sieve analysis was carried out on each of the samples of soil retained on a sieve with 0.075 mm opening while hydrometer analysis was performed on the fraction of the soil passing this sieve, using sodium hexametaphosphate. The index properties tests conducted on each of the soil samples were performed in accordance with procedures stated in [5].

The standard proctor energy and the modified proctor energy were used to prepare specimens for compaction and CBR tests, respectively. After curing the specimens for CBR tests for 6 days under controlled temperature (25 ± 2°C) and relative humidity (100%), the specimens were afterwards immersed in water for 24 hours before testing to determine their soaked CBR values [6]. Specimens for unsoaked CBR tests were cured for 7 days under the controlled temperature.

Constant-head permeability apparatus was used to determine the coefficient of permeability of the soil samples.

3. Results and discussion

3.1 Moisture content determination

The results of the natural moisture content determination for the soil samples are presented in Figure 4. It shows that the natural moisture contents of the samples range from 15–18%, with the samples denoted as WK1 and AG1 having the highest and least natural moisture contents, respectively. It is necessary to know the in-situ moisture condition of soils to be used for earthworks. This will aid the determination of the in-situ states of the soil samples and the amount of water to be added or the degree of drying required to bring the soil samples to their maximum dry unit weight.

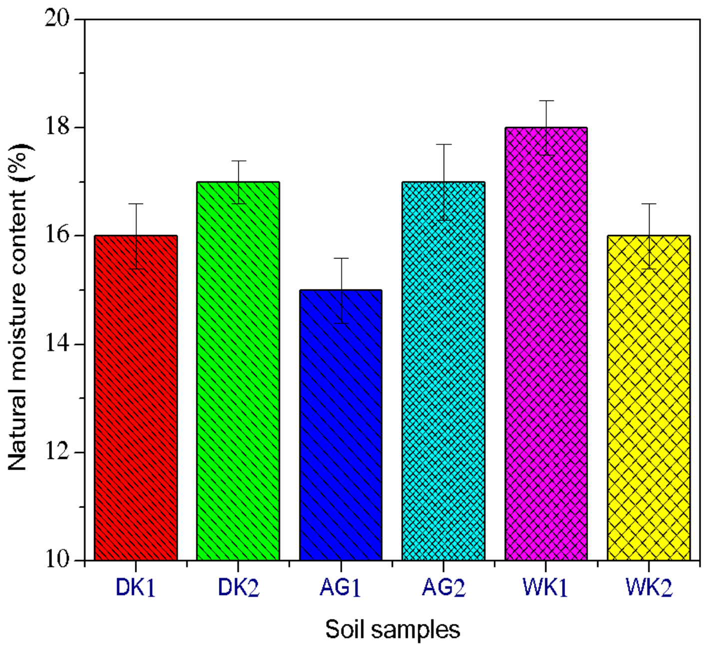


Figure 4: Natural moisture content of the soil samples

3.2 Specific gravity determination

Figure 5 shows the specific gravities of the samples. The specific gravities of the samples range from 2.68–2.78. The lower and upper bound of this range of specific gravities were obtained for DK2 and AG1, respectively. On the average, the soil samples derived from migmatitic rocks have a higher specific gravity than the average specific gravity of those derived from charnockitic rocks.

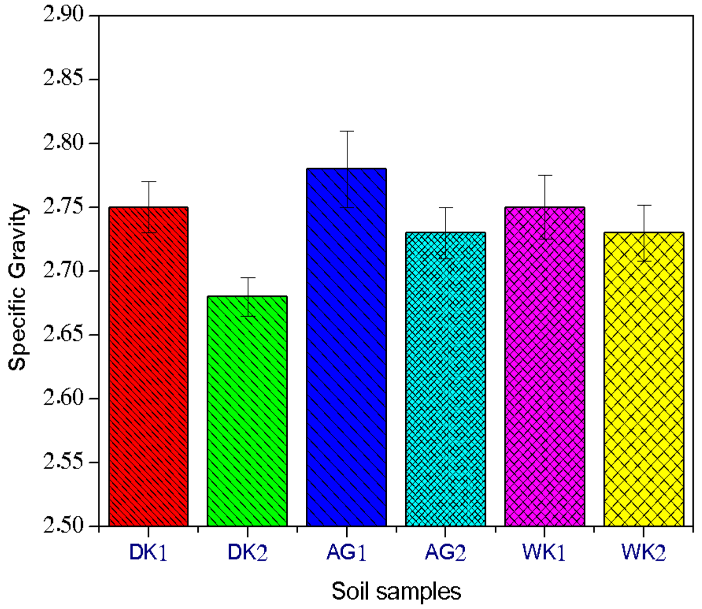


Figure 5: Specific gravities of the soil samples

3.3 Sieve and hydrometer analyses

The results of sieve and hydrometer analyses are presented in Figure 6 in form of the particle size distribution curves for each of the soil samples. Samples AG1 and DK1 are coarse-grained with less than 20% of each of their particles passing through the 75 μm sieve. The uniformity coefficient and coefficient of curvature for sample AG1 are 17.8 and 0.63, respectively. Samples WK2 and DK2 are also coarse-grained (having less than 50%, but greater than 40%, of each of their particles passing through the 75 μm sieve). Consequently, the clay fractions in samples WK2 and DK2 influence their geotechnical properties. Samples AG2 and WK1 are fine-grained.

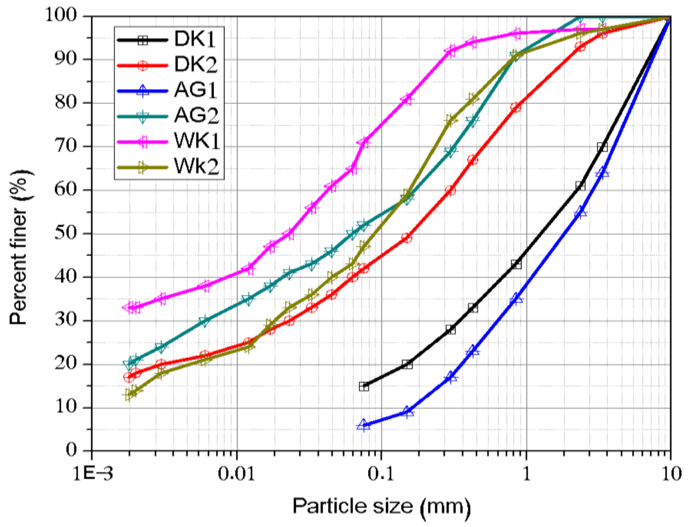


Figure 6: Particle size distribution of the soil samples

3.4 Liquid, plastic and linear shrinkage determination

The results of the determination of liquid, plastic and linear shrinkage limits, and plasticity index for each of the samples are graphically illustrated in Figure 7. Figure 7 shows that the liquid limits of all the samples are less than 50%. The samples (AG1 and AG2), derived from charnockitic rocks, were found to be non-plastic. Plots of plasticity index against liquid limit showing the classification of the soil samples, derived from the charnockitic and magmatitic rocks, according to the Unified Soil Classification (USC) and American Association of State Highway and Transportation Officials (AASHTO) systems are presented in Figure 8.

Figure 8(a) shows that the fine-grained fraction of samples DK1 and DK2 are predominantly silt of low plasticity while that of WK1 and WK2 comprise of approximately equal proportions of clay and silt with low plasticity. Figure 8(b) shows that the fine-grained fraction of samples DK1, DK2, WK1 and WK2 are classified as A-7-6 soils, according to AASHTO system. Generally, the soil samples from charnockite are lower on the plasticity chart than those of the migmatite. Tables 1 and 2 presents the classification of the soil samples, according to USC and AASHTO systems, respectively. The samples derived from charnockitic rocks were mostly categorized as having poor subgrade rating (Table 2).

Table 1. Soil samples classification according to USC system

Sample	Class	Description
DK1	SC	Clayey sand
DK2	SC–SM	Clayey sand with silt
AG1	SW–SM	Well-graded sand with silt
AG2	ML	Silt
WK1	CL	Lean clay
WK2	SC–SM	Clayey sand with silt

Table 2. Soil samples classification according to AASHTO system

Sample	Class	AASHTO subgrade rating
DK1	A–2–7	Good
DK2	A–7–6	Poor
AG1	A–3	Good
AG2	A–4	Fair
WK1	A–7–6	Poor
WK2	A–7–6	Poor

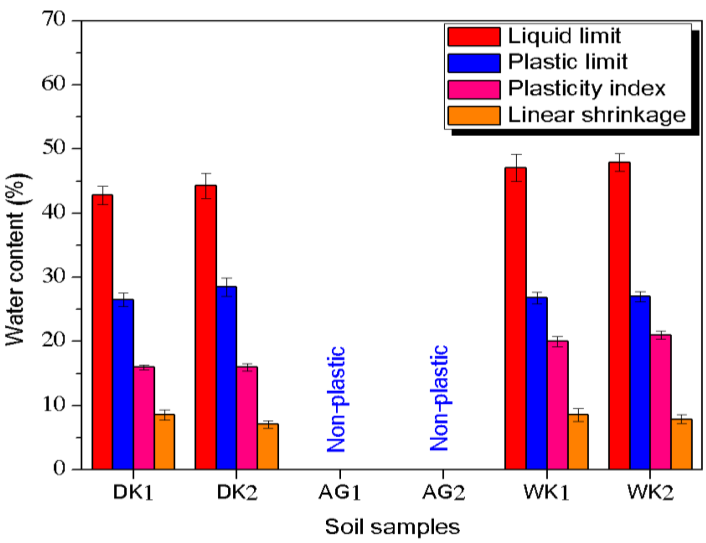
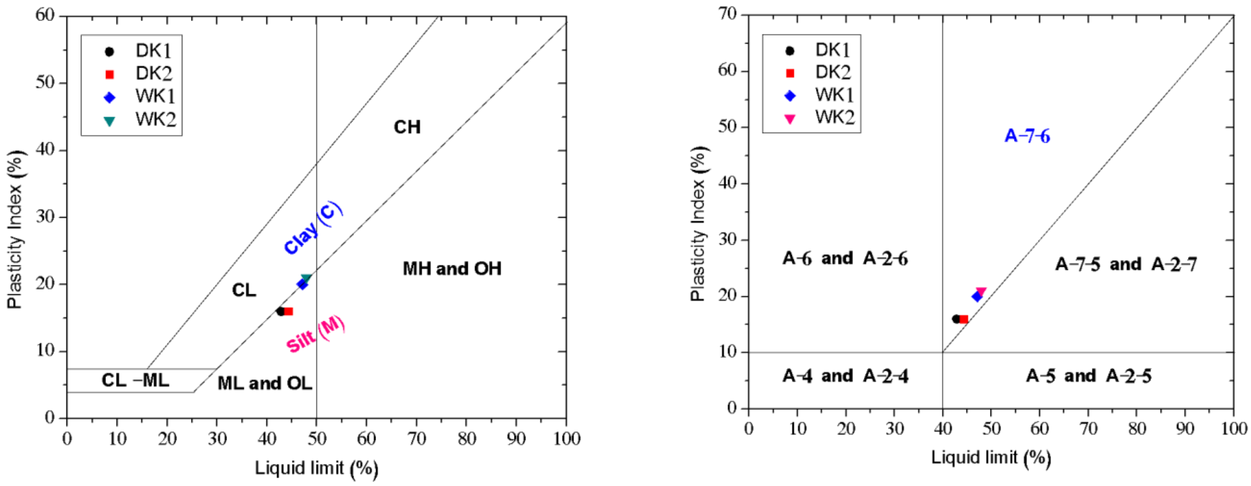


Figure 7: Atterberg limits of the soil samples

3.5 Compaction test

The compaction characteristics of the soil samples are shown in Figure 9. The mean optimum moisture content (OMC) and mean maximum dry unit weight of the samples derived from charnockitic rocks are 18.5% and 17.03 kN/m^3, respectively. On the other hand, the mean OMC and mean maximum dry unit weight of the soil samples derived from migmatitic rocks are 20% and 15.65 kN/m^3, respectively.



(a) (b)

Figure 8: Soil classification of the samples according to (a) USC and (b) AASHTO systems

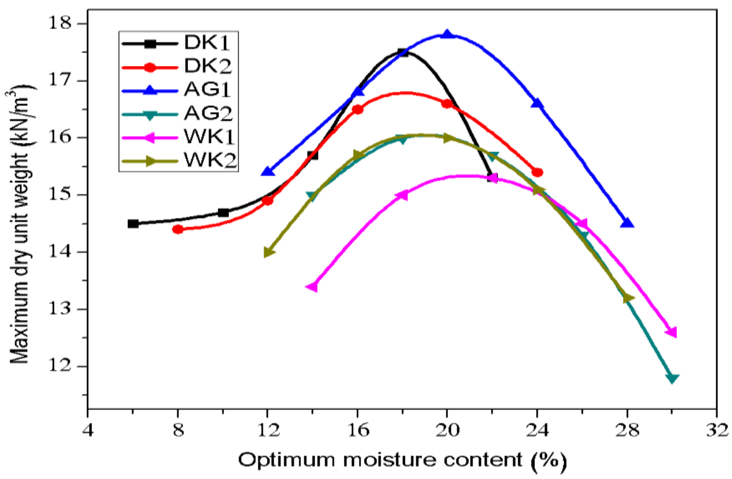


Figure 9: Compaction characteristics of the soil samples

3.6 California bearing ratio test (CBR)

The unsoaked and soaked CBR values for the soil samples are graphically illustrated in Figure 10. The gravelly content of samples DK1 and AG1 (Table 1) seem to have been chiefly responsible for their high unsoaked and soaked CBR values. The soils derived from charnockite have their average unsoaked CBR and soaked CBR to be higher than those of the soils derived from migmatite by 64.7% and 73.5%, respectively. The results of the unsoaked and soaked CBR tests seem to further buttress the AASHTO subgrade ratings (Table 2) of the soil samples.

3.7 Permeability test

Figure 11 presents the results of the permeability tests conducted on the soil samples. The coefficients of permeability for samples DK1 and AG1 are higher than those of the other samples. This may be attributed to the higher gravel fraction in these samples, which resulted in more inter-particle void spaces. The coefficients of permeability for samples WK1 and WK2 are generally lower than those of the other samples because of their higher clay contents.

When a residual soil is formed, the type of rock that was broken down to form the soil influences its properties [6, 7]. It becomes important to identify the parent rock of a residual soil to be assessed for use as road pavement layer materials. Several researchers [8, 9] have investigated the suitability of using locally-available soils as pavement layer materials for road construction by assessing their geotechnical properties but rarely have researchers combine these evaluations with identification of the parent rock that formed the investigated soils.

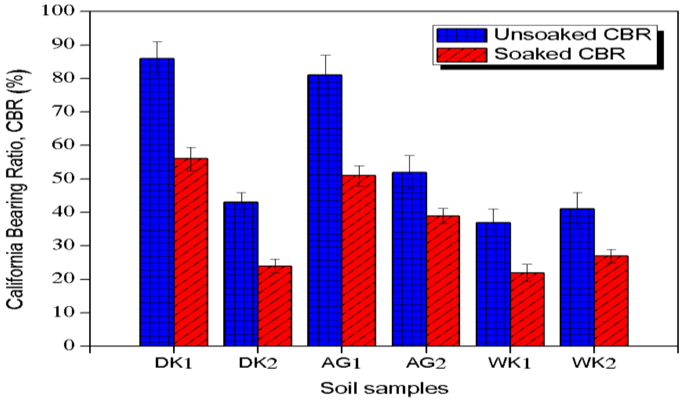


Figure 10: CBR of the soil samples

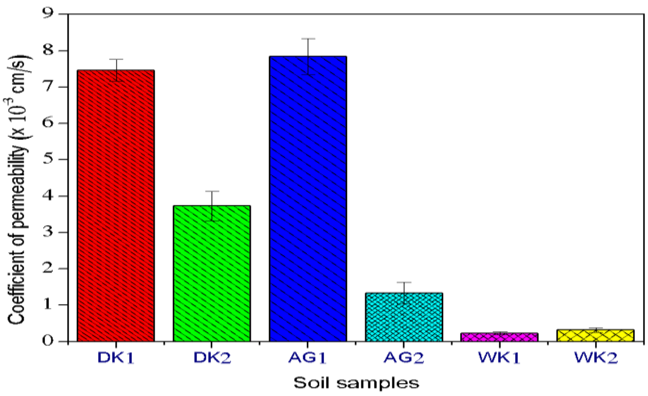


Figure 11: Permeability of the soil samples

The suitability of the soil samples, investigated by this research work and which originated from either magmatitic or charnockitic rocks, for use as subgrade, subbase or base layer materials for road pavement earthworks was determined by comparing the properties of each of the soil samples with local standard requirements of the Nigerian General Specification [10]. The main criteria for selecting soil samples for subgrade, subbase and base applications in accordance with the Nigerian General Specification [10] are summarily presented in Table 3. These criteria are different from what is obtainable in other parts of the world such as Europe and America, where pavement layer materials are subjected to different climatic conditions (for example, frost action).

Table 3. Subgrade, subbase and base requirements (Nigerian General Specification 1997)

Criteria	Subgrade	Subbase	Base
Proportion passing 75 μm sieve (%)	≤35	≤35	≤35
Liquid Limit (%)	≤80	≤35	≤35
Plasticity Index (%)	≤55	≤12	≤12
Soaked CBR (24 hours)	Any value	≥30	≥80

The criterion on the proportion of the soil passing the 75 μm sieve disqualifies samples DK2, AG2, WK1 and WK2 from being directly used as subgrade, subbase or base materials. Since the liquid limits of the soil samples (DK1, DK2, WK1 and WK2) derived from charnockitic and migmatitic rocks are higher than 35%, their utilization as road pavement layer material is limited to subgrade application. The plasticity index requirement (Table 3) also limits the application of the samples derived from charnockitic rocks to subgrade applications. Based on the soaked CBR requirement in Table 3, samples DK1, AG1 and AG2 satisfies the subbase requirement while samples DK2, WK1, and WK2 satisfies the subgrade requirement.
Considering all the criteria in Table 3, only sample AG1, derived from charnockitic rocks, satisfies all the requirements for use as subbase layer material for road pavement construction. Also, only sample DK1, derived

from charnockitic rocks, satisfies all the requirements for use as subgrade layer material. Samples DK2, AG2, WK1 and WK2 will need to be stabilized before they can meet the requirement for use as subgrade or subbase materials. Conventional soil stabilizers that can be used include Portland cement [11] and lime [12]. However, recent research works have favoured the use of waste materials as low-cost stabilizers. Some low-cost stabilizers or modifiers that can be used to improve the geotechnical properties of these soils include pulverized steel slag [13-16], waste marble fines [17, 18], pulverized asphalt [19-21], mucilage of cactus cladodes [22], bottom ash [23] and corncob ash and cement blends [24].

Conclusions

This research work investigated the possibility of using some soils derived from charnockite and migmatite as road pavement layer materials. Based on the research results obtained, on the average: (i) the samples derived from migmatite were found to have higher specific gravity, plasticity and OMC than those derived from charnockite; (ii) the samples derived from charnockite were found to have higher maximum dry unit weight, unsoaked and soaked CBR values, and permeability; (iii) the samples AG1 and DK1, derived from charnockite, meets the requirements for use as subbase and subgrade road pavement layer materials, respectively.

The geotechnical properties of the other samples need to be improved, if they are to be useful for road construction. This research work is unique in that it identifies the parent rocks from which the investigated soils were form before benchmarking their geotechnical properties with existing local standard requirements. Also, the massive characteristic with medium to coarse grained texture of charnockitic rocks made its samples more suitable as subgrade layer material for road pavement. This work, thus, provides a quick reference material (for soil selection), accessible to relevant local government agencies, highway engineers, geologists and contractors, while planning for road pavement construction using soils similar to those used in this study.

References

1. Kinuthia J. M., Nidzam R. M. *Waste Manag.* 31 (2011) 1867.
2. Obuzor G. N., Kinuthia J. M., Robinson R. B. *Eng. Geol.* 151 (2012) 112.
3. Talabi A. O. *RMZ_M&G* 60 (2013) 73.
4. Talabi A. O., Tijani M. N. *Appl. Water Sci.* 3 (2013) 229.
5. BSI BS 1377: 1990 *British Standards Institution* (1990) London.
6. Badia D., Marti C., Aznar J. M., Leon J. *Geoderma* 193–194 (2013) 13.
7. Rowell D. L. *Taylor & Francis* (2014) New York.
8. Elarabi H., Taha M., Elkhawad T. *Sudan Eng. Society J* 59 (2013) 41.
9. Amadi A. N., Akande W. G., Okunola I. A., Jimoh M. O., Francis D. G. *Amer. J. Mining and Metall.* 3 (2015) 15.
10. Nigerian General Specifications Roads and Bridges *Federal Ministry of Works* (1997) Lagos.
11. Jaritngam S., Somchainuek O., Taneerananon P. *Iranian J. Sci. Tech. - Transact of Civ. Eng.* 38 (2014) 275.
12. Beetham P., Dijkstra T., Dixon N., Fleming P., Hutchison R., Bateman J. *Proc. of the Institut. of Civ. Eng. – Ground Improv.* (2014) Ahead of print, 1.
13. Akinwumi I. I., Adeyeri J. B., Ejohwomu O. A. *Proc. 2nd Int. Conf. on Sustainable Design Eng. and Constr. ASCE* Texas (2012) 457.
14. Zhu G., Hao Y., Xia C., Zhang Y., Hu T., Sun S. *J. Mining and Metal Section B: Metallurgy*, 49B (2013) 217.
15. Aziz M. M. A., Hainin M. R., Yaacob H., Ali Z., Chang F.–L., Adnan A. M. *Mater. Res. Innov.* 18 (2014) S6-255.
16. Akinwumi I. *PeriodicaPolytechnica Civil Eng*. 58 (2014) 371.
17. Okagbue C. O., Onyeobi T. U. S. *Eng. Geol.* 53 (1999) 371.
18. Akinwumi I. I., Booth C. A. *J. Env. Eng. Landscape Manage.* 23 (2015) 121.
19. Edeh J. E., Eberemu A. O., Agnes O. *Adv. Mater. Res.* 367 (2012) 3.
20. Bocci M., Manganaro A., Stramazzo V., Grilli A. *Adv. Mater. Res.* 723 (2013) 1044.
21. Akinwumi I. I. *Int. J. Sci. Eng. Res.* 5 (2014) 631.
22. Akinwumi I. I., Ukegbu I. *Geomech. Eng.* 8 (2015) 649.
23. del Valle-Zermeno R., Chimenos J. M., Giro-Paloma J., Formosa J. *Chemosphere* 117 (2014) 402.
24. Akinwumi I. I., Aidomojie O. I. *Int. J. Geomatics Geosci.* 5 (2015) 375.