# ENGINEERING INDEX PROPERTIES OF THE NUMANHA BLACK COTTON SOIL IN GUYUK AREA, NORTHEASTERN NIGERIA

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**Abstract:** Structural failure along the Numan-Gombe road around Guyuk area is manifested in pavement distress and this is due mainly to insufficient strength of the Numanha black cotton soil that covers that area. Twelve (12) samples randomly collected from the soil were subjected to standard laboratory test specified by British Standard (BS) 1377. X – ray diffraction analysis using Philips - PW 1011 model diffractometer was also done to ascertain the suitability of the soil for road pavement. The results showed that the soil is poorly graded sandy clay and classified as A – 7 – 5 type; mineralogical analyses portray illite as the dominant clay mineral. Liquid limit, plastic limit and plastic index and linear shrinkage showed average values of 68, 32, 35 and 15%, respectively. Maximum dry density and optimum moisture content averages at 1769 Kg/m$^2$ and 16.7%, respectively. Average in-situ void ratio of 0.665 decreased to an average value of 0.385 while coefficient of compressibility decreased from average values ranging from 0.553 – 0.048 m$^2$/KN as pressure increased. Results which suggest that the soil exhibits poor engineering qualities because of its high optimum moisture content, low dry density, low permeability, high compressibility and shrinkage. This is due to its high clay proportion possessing the tendency to swell and shrink repeatedly during alternate wet and dry seasons and hence do not meet the Nigerian standard for pavement materials.

**Keywords:** Engineering, shale, cotton soil, compressibility, compaction, subgrade

## Introduction

Black cotton soils are residual deposits which are generally susceptible to differential settlements caused by differential volumetric changes in moisture (VenkaraMuthyalu *et al*., 2012; Bairwa *et al*., 2013). They are rich in montmorrillonite which is responsible for its expansive nature. When its parent rock is abundant in potash bearing mineral, it may contain illite (Tamhane and Namjoshi, 1959); the soil is problematic for engineering construction (Eberemu and Sada, 2013; Kanawi and Kamel, 2013). The engineering properties of soils are quite indispensable in the determination of suitability of soils in engineering practice. Since most engineering works are constructed on or with soil masses, it is essentially crucial to ascertain the compatibility of such soils as subgrade material (Oladeji and Raheem, 2002; Okunade, 2007). Roads as engineering structures are constructed on soils and their durability/failure is dependent mostly on the soil as foundation material. Failures on Nigerian roads are as a resultof poor understanding of engineering properties of the soils underlying such road pavements. Adeyemi (1995) emphasized influence of inherent properties of parent rock on engineering properties of subgrade soil. Hence, adequate understanding of the geology that underlies the area is imperative; this is because the structure requires strong and long-lasting support from its subsurface material (Okogbue and Uma, 1988).

Shales are considered one of the most preponderant sedimentary rocks on earth. Guyuk and environs in Adamawa state, northeastern Nigeria is underlain by shales of the Numanha Formation (Odebode, 1983). These shales are well exposed and attacked by weathering process leading to the formation of the Numanha black cotton soil. Shales are known to possess certain properties such as high compressibility, low shear strength and critical degree of expansion that make them problematic. According to Okogbue (1989), the problems related with shales in shaley terrains are mostly influenced by their mineralogy. Ajayi (1982) observed that road failure are more prevalent where pavement was founded on weathered layer rather than strong lateritic layers. Regular undulating spots that later developed into crocodile cracks are major features suggesting foundational problemsor failure are very common on the road stretch especially between Numan and Guyuk. Such bad spots on our roads constitute death snares to road users. Hence, utilization of soils requires adequate understanding of the properties and factors affecting their behavior and performance as subgrade materials (Ademilua, 2017)

Therapid changes in the vertical and horizontal distribution of the soils and the clay types necessitatesa detailed determination of engineering properties of the soil as foundation materials for future planning, development, construction, management and safety of structures built on the soil.

## Materials and Method

### *Location and geology*

Guyuk lies between latitudes 9$^o$52' 44"N, 9$^o$ 54' 20"N and longitudes 11$^o$56' 10"E, 11$^o$ 58' 55"E (Fig. l), the area is underlain by the Numanha Shale which was first recognized by Barber *et al*. (1954) and was described as “Argillaceous beds.” The upper section is exposed at the Numanha stream near Lamja where the lithology consists of shales with occasional bands of sandstone, mudstone and limestone. The lower part consists of grayish black shales with nodular mudstones and contemporaneous lava flow. The age of the Numanha Formation is Santonian (Cratchley and Jones, 1965); the shales in this area are well exposed and as a result they are attacked by weathering leading to the formation of the Numanha black cotton soil.

### *Methodology*

Twelve (12) representative soil samples were collected randomly from different locations at a depth of 2.0 m. Grain size analyses and Atterberg limits were undertaken according to the British Standard Specification (BS) 1377 (1990). The Atterberg limit tests were conducted with about 300 g of soil samples passing 0.425 mm sieve. Other tests carried out included: moisture content test, specific gravity test, compaction test using the standard proctor mould (4.5 kg rammer), permeability test using the constant head permeameter and consolidation test.

Mineralogical analyses were by X-ray diffraction (XRD) method in which sample powders were analyzed using a Philips - PW 1011 model diffractometer. The diffraction diagram was recorded using a 2θ scale (glancing angle of reflection) against the peak intensities. Interpretation was by comparing curves with peaks of notable intensities with those of standard minerals established by Pei - Yuan Chen (1977).

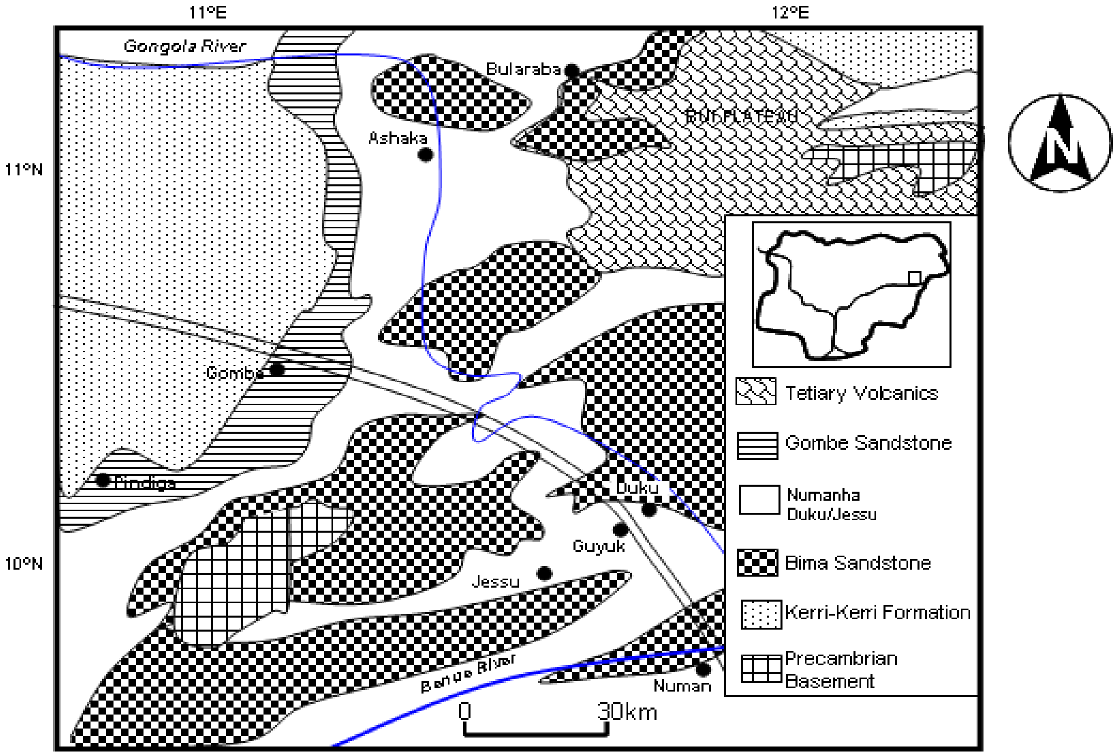


**Fig. 1: Geological map of Guyuk and environs (modified after Carter *et al.*, 1963)**

**Results and Discussion**

***Grain size analysis***

Grain size distribution is an essential aspect of soil mechanics and engineering geology because it is an index of other engineering properties of soils such as compressibility and shear strength. Results of grain size distribution are summarized in Table 1 and shows that the soils havehigh fractions of sand (average value of 56%) followed by notable proportion of fines (average of 41% for clayand 3% for silt). There was no fraction coarser than 2 mm indicating the deficiency of gravel; gravelly soils usually have good bearing capacity and usually undergo little consolidation when load is placed on them. The graph of grain size distribution (Fig. 2) shows that the soil ispoorlygraded and texturally identified as clayey sand. The relatively high proportion of fines and absence of gravelly fractionsrender the soil unsuitable for construction purposes. This observation was collaborated by earlier researchers (Uduji *et al*., 1994; Fakeye *et al*., 2016; Ademilua, 2017) who identified the preponderance of fines and absence of gravels in subgrade materials as responsible for structural failures of roads in different parts of Nigeria. Poor grading of soils accounts for instability and low strength of the soil making them unsuitable for engineering construction purposes. This observation gives support to the fact that the Numanha black cotton soils are problematic.

***Mineralogical analysis***

Figure 3 shows result of the X - ray diffraction analyses. Conspicuousillite diffraction peak was detected at 3.32 Å; notable kaolinite peaks were reflected at 3.56 Å, 4.44 Å and 7.13 Åwhilequartz and dickite were present at 4.26 Å and 4.44 Å, respectively. The results show that illite, kaolinite and quarthz are the dominant minerals constituting about 48.0, 37.1 and 12.9%, respectively. The high proportion of illite and kaolinite in the soil is due to the fact that the soil was derived from the weathering of the Numanha Shales, since they are the dominant clay minerals that occur in soils especially those derived from shales.

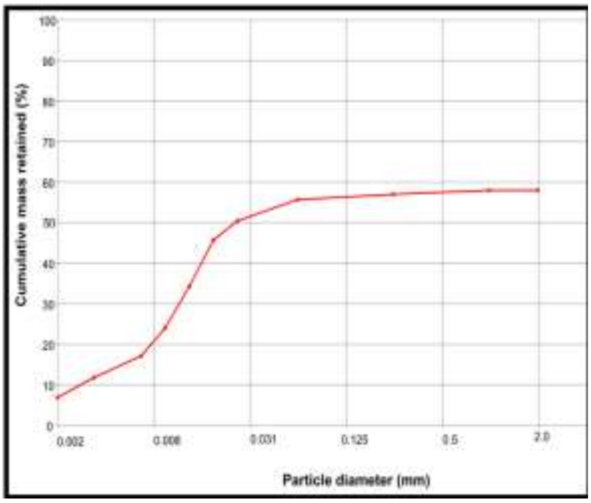


**Fig. 2: Typical grain size distribution curve of Numanha black cotton soil**

***Natural moisture content (NMC)***

The moisture content of the soil which is an indication of shear strength as shown in Table 1 rangedfrom 17.50 – 19.80%. The result shows that the soil has an average moisture value of about 18.78%. This portrays the soil as having relatively high natural moisture content; because these values are higher than the average range of 5 – 15% specified by FMWH (2000) for construction purposes. The high values of moisture content can cause swelling of the soil and decrease in shear strength which can result in immediate failure of road pavements and other engineering structures.

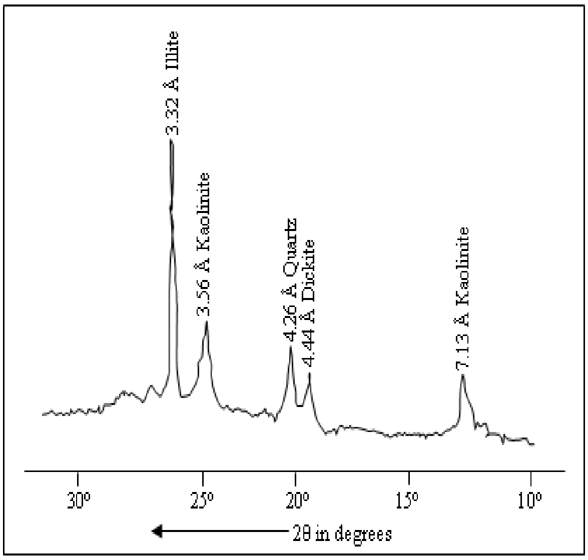


**Fig 3: X-ray diffractogram of Numanha black cotton soil of Guyuk area**

**Table 1: Engineering properties of the Numanha black cotton soil**

| Index | Minimum | Maximum | Average Values |
|---|---|---|---|
| Sand | 54 | 60 | 56 |
| Silt | 1 | 4 | 3 |
| Clay | 39 | 42 | 41 |
| Natural Moisture content (%) | 17.50 | 19.80 | 18.78 |
| Liquid Limit (%) | 68 | 70 | 68 |
| Plastic Limit (%) | 30 | 34 | 32 |
| Plastic Index (%) | 30 | 38 | 35 |
| Linear Shrinkage (%) | 10 | 19 | 15 |
| Maximum Dry Density (Kg/m$^3$) | 1750 | 1790 | 1769 |
| Optimum Moisture Content (%) | 16.28 | 17.30 | 16.67 |
| Specific Gravity | 2.66 | 2.96 | 2.80 |
| Permeability (cm/s) | 9.7 x 10$^{-7}$ | 1.3 x 10$^{-6}$ | 1.87 × 10$^{-6}$ |

***Atteberg limits***

The summary of liquid limits, plastic limits, plastic index and linear shrinkage of Numanha black cotton soil are presented in Table 1. The liquid limits ranged from 67 – 70%, plastic limits ranged from 30 – 34%, plastic index ranged from 30 – 38 while linear shrinkage ranged from 10 – 15%. The results of Atterberg limits show that the soil has high plasticity,high linear shrinkage and high swelling potential.The high swelling potential can cause cracking on the roads constructed on this soil because exposure of the soil to water, a local expansion of the pavement is possible. According to Cattell (1998), the high plasticity couldbedue to the weathering taking place in the area. Weathering of clays tends to increase their plastic properties and the highplasticity could beresponsible for the high linear shrinkage value (Akpokodje *et al*., 1991). From the results, it shows that the soil behaves as a viscous liquid because of its high liquid limit and has only the water pressure to resist stress. This results in soils of low strength in relation to imposed loads. The Casagrande plot of plasticity indices against liquid limit as modified by Bells (2007) and shown in Fig. 4, classify the Numanha black cotton soil as inorganic clay with high compressibility. Soilswith high plasticity according to Coduto (1999) are usually susceptible to high compressibility. The Numanha black cotton soil have high to very high swelling potential based on the relationship between plastic index and swelling potential by Alao (1982). Adeyemi (1992) recommended that soils with linear shrinkage lower than 8% as good sub-base materials. The values of linear shrinkage obtained from the analyses of the Numanha black cotton soil are higher than 8% which disqualifies the soil as a good subgradematerial. Furthermore, Lucian (2006) observed that when plastic index is greater than 31%, it is an indication of presence of high content of expansive clays suchas illite or illite-montmorrilonite mixed layer. Quantitative analyses of X-ray diffractogram (Fig. 3) confirmed the presence of illite as the predominant clay mineral.

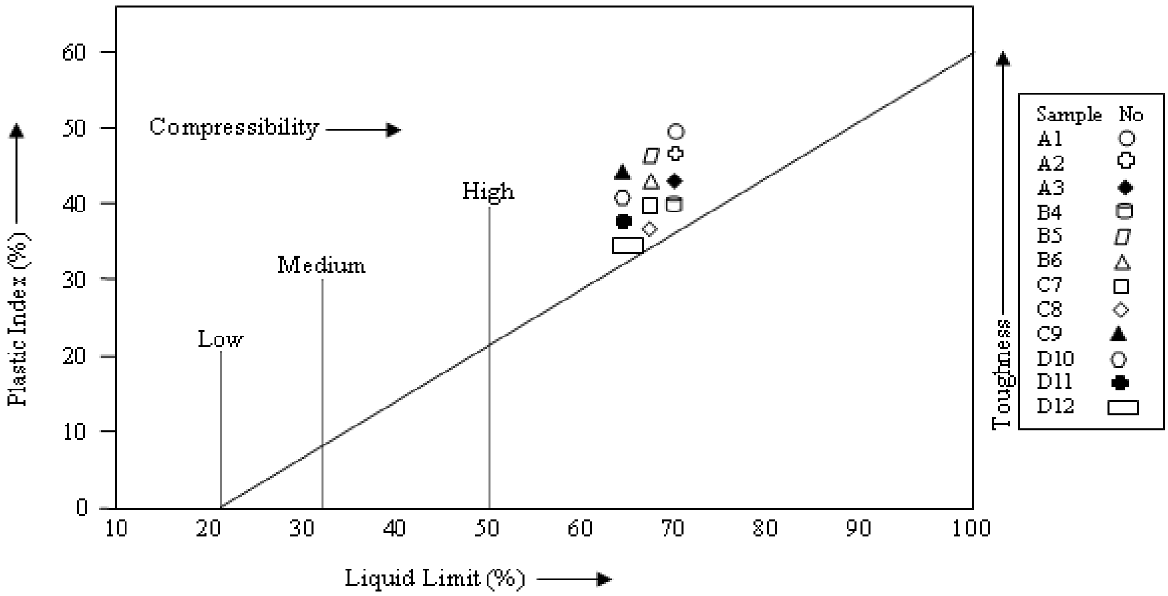


**Fig 4: Plasticity chart for classification of soil**

***Compaction test***

The result of the compaction test shown in Fig. 5 and Table 1 indicates that the average optimum moisture content is 16.67% while the average maximum dry density is 1690 kg/m$^3$. The results showed that the compacted densities are low while optimum moisture content is high.

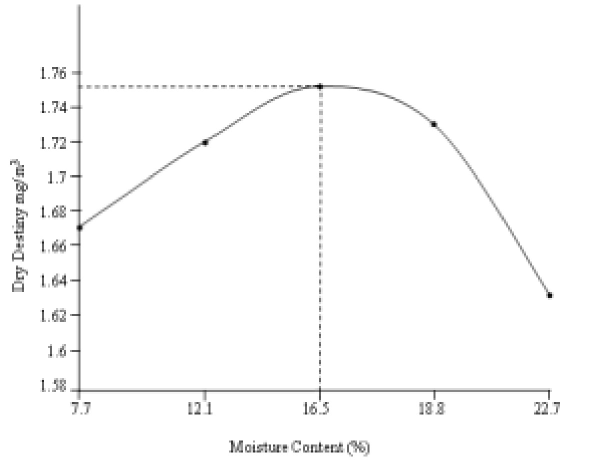


**Fig. 5: Typical compaction curve of Numanha black cotton soil**

Dry density of soils gives appropriate information on its gradation and it is a very important parameter that affects soil reaction to stress. The low maximum dry density is due to increase in proportion of fines as indicated by grain size distribution while the high optimum moisture content is due to high plasticity of the Numanha black cotton soil. The lower maximum dry density and higher optimum moisture content may also be attributed to its higher water affinity and greater swelling potential when in contact with water but shrink when water is withdrawn. The effect of such volume change is that the soil has a lesser resistance to settlement and hence particles tend to be kept apart giving low dry densities and high void ratios. This produces improper compaction which could lead to failure of the pavement and as a result; the soil is not a suitable subgrade material for construction purpose. The best soils for subgrade material are soils with high maximum dry density at low optimum moisture content (Jegede, 1999).

***Specific gravity***

The results of specific gravity of soil samples (Table 1) ranged from 2.66 – 2.96. All the Numanha black cotton soil samples of Guyuk area have an average specific gravity of 2.80 and met the specified gravity standard of greater than 2.6. Though the specific gravity and invariably the density of the soil are high, the high moisture content of the soil would jeopardize the positive effects of this on consolidation of the soil.

***Permeability test***

The result of the permeability test (Table 1) indicate that the permeability values range from 9.7 x $10^{-7}$ cm/s to 1.3 x $10^{-6}$ cm/s. Average permeability value of 1.87 x $10^{-6}$ $cms^{-1}$ indicate that the Numanha black cotton soil contain a lot of water and are impermeable. The soil qualifies as impervious soil because permeability; K is less than 0.115 x $10^{-6}$ cm/s based on the classification of permeability by Malomo *et al*. (1983). The low permeability is attributed to the clayey nature of the soil and this gives the soil a high water holding capacity. Generally, soils which contain a lot of water are not good for engineering construction purposes since water causes an increase in stress, and also a reduction in the soil strength. This disqualifies the black cotton soil of Guyuk area as a suitable sub-grade material for engineering construction.

***Consolidation test***

The results of the consolidation test as shown in Fig. 6 shows the relationship between void ratio and applied pressure. The trend of the graph shows that during loading stages of the soil samples, the void ratio decreased as applied pressure increased up to a maximum pressure of 1600 KN/$m^2$. The results indicated that average in-situ ratio of 0.665 decreased to an average value of 0.575 when applied pressure was 100 KN/$m^2$ and further decreased to an average value of 0.385 when applied pressure was increased to 1600 KN/$m^2$. The graph of Fig. 7 shows the coefficient of compressibility against applied pressure. It can be observed from the graph that as pressure increased there was a decrease in coefficient of compressibility from an average values ranging from 0.553 – 0.048 $m^2$/KN.

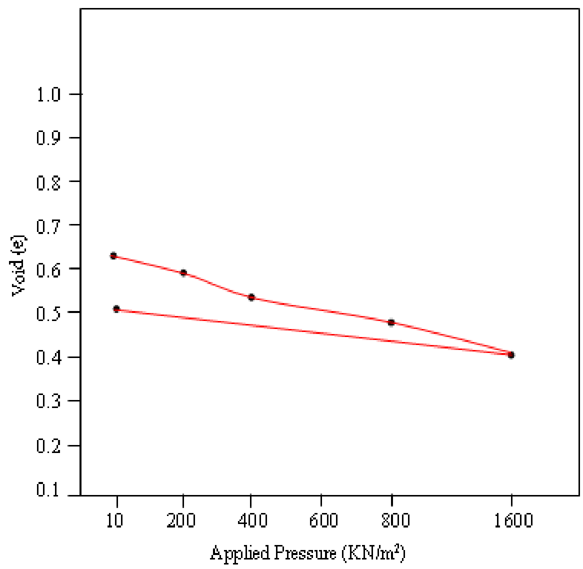


**Fig. 6: Typical graph of void ratio against applied pressure of Numanha black cotton soil**

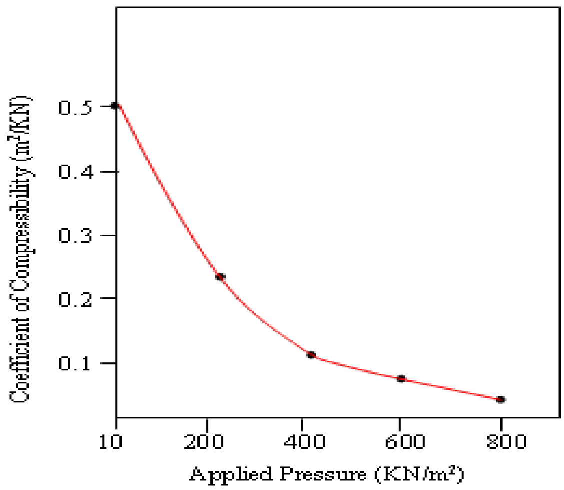


**Fig. 7: Typical graph of compressibility against applied pressure of Numanha black cotton soil.**

The observed trend of decrease in void ratio and coefficient of compressibility against pressure points to likelihood of substantial settlement (total or differential) which normally causes a lot of foundation problems such as bearing capacity failure. This happen because the soil is incapable of supporting of the structural load on top of it. Consolidation refers to the process by which soil changes volume gradually in response to change in pressure; this happens because soils comprises of grains and a pore-filled matrix. When soils are subjected to an increased load, water diffuses away until the matrix gradually takes up the pressure change and thus shrinks in volume. The consolidation test clearly shows that the soil is highly compressible and has low strength, this mostly due to the high proportion of clay (42%) in the soil; this view was also supported by the high Atterberg limit and linear shrinkage.

**Conclusions and Recommendations**

The Numanha black cotton soil of Guyuk area derived from weathering of shales of the Numanha Formation was investigated to determine their suitability as subgrade materials for road pavements and other engineering applications.The Grain size analyses shows that the soil is poorly graded with absence of gravels and mean proportion of fines (silt and clay) of about 44%. This indicates the inability of the soil particles to provide substantial strength and renders the soil unsuitable for road construction purposes. Atterberg limit test shows that the soil has high plasticity, high swelling potential and thus low strength. The trend observed from the compaction test indicates that the soil has a very low resistance to settlement while consolidation parameters points to a likelihood of substantial settlement. These properties would most likely negate the few favourable properties like high specific gravity and invariably density of the soil.

Mineralogical studies show that, the soil contains mainly illite, kaolinite and quartz; the high clay content of the soil must have been responsible for the low coefficient of permeability and high compressibility of the soil. The high natural moisture content also lowers the strength and dry density of the soil and this would also make compaction in the field difficult.

A synthesis of the mineralogical and geotechnical data suggests that the soil of Guyuk area is poor subgrade materials. They do not meet the Nigerian standard for pavement materials due to their poor engineering properties and mineralogical composition. Stabilization using lime or cement is required before they can serve as good subgrade materialsfor road construction. On the other hand, it is recommended that excavation of the soil andsubsequent refilling with laterites should be undertaken during road construction. Also, to minimize present pavement problems in the area, adequate drainage should be provided on either side of the road to keep water content constant and preclude inundation of the sub-grade with water.

**Conflict of Interest**

Author declares that there is no conflict of interest.

**References**


Ademila O 2016. Application of geophysical survey for subsurface investigation of an erected multistory building in southwestern Nigeria. *Int. Basic and Appl. Res. J.*, 2(12): 1-12.

Ademila O 2017. Geotechnical characterization of subgrade soils in southern part of Nigeria. In: *Proce. Second Int. Conf. Nig. Assoc. Engr. Geol. and Envt.*, Lagos, pp. 42- 48.

Adeyemi GO 1992. Highway geotechnical properties of laterised residual soils in the Ajebo-Ishangeological transition zone of Southwestern Nigeriaarea. Unpublished Ph.D thesis, OAU, Ile-Ife, Nigeria.

Adeyemi GO 1995. The influence of parent rock factor on some engineering index properties of three residual laterised soils in southwestern Nigeria. *Bull. Assoc. Engr. Geol.*, Paris, 52: 3-8.

Ajayi TRA 1982. Geotechnical basis failure of section of Lagos-Ibadan expressway, southwest, Nigeria. *Bull. Engr. Geol. & Envt.*, 20: 25-31.

Akpokodje EG, Etu-Efeotor JO & Olorunfemi BN 1991. The composition and physical properties of some ceramic and pottery clays of southeastern Nigeria. *Journal of Mining and Geology*, 27(1): 1-8.

Alao DA 1982. Engineering properties of laterites from Ilorin, Nigeria. *Engineering Geology*, 19: 111-118.

Bairwa K, Saxwna AK & Arora TR 2013. Effect of lime and fly ash on engineering properties of black cotton soil. *Int. J. Emerging Techn. and Advanced Engr.*, 3(11): 535-541.

Barber W 1954. The Geology of Lower Gongola. Annual Report, Geological Survey Nigeria (1952-1953), 18-20.

Bell FG 2007. Engineering Geology, 2nd Edition. Elsevier, London, United Kingdom, 207-248.

British Standard 1990. Methods of testing soils for civil engineering purposes, British Standard Institution, London.

Carter JD, Barber W, Tait EA & Jones GP 1963. The Geology of parts of Adamawa, Bauchi and Bornu Provinces in Northeastern Nigeria. *Bull. Nig. Geol. Survey*, 30, l09pp.

Cattell AC 1998. The development of high plasticity clay soils through weathering of Devonian slates in south Devon, south-west England. *Geoscience*, 9: 209-213.

Coduto DP 1999. Geotechnical Engineering, Principles and Practices. Prentice-Hall, New Jersey, 759pp.

Cratchley CR & Jones JP 1965. An interpretation of the geology and gravity anomalies of the Benue Valley, Nigeria. *Overseas Geol. Survey and Geophy.*, l: 1-26.

Eberemu AO & Sada H 2013. Compressibility characteristics of compacted black cotton soil treated with rice husk ash. *Nig. J. Techn.*, 32(3): 507-521.

Fakeye AM, Osadebe CC, Aitsebaoma FO, Matawal DS &Lamidi RB 2016. A GIS based approach to mapping and visualizing engineering soil data. In: *Proc. First Int. Conf. Nig. Assoc. Engr. Geol. and Envt.*, Lagos, pp. 83-92.

Federal Ministry of Works and Housing. 2000. General specification for roads and bridges, 2: 137-275.

Jegede G 1999. Engineering geological significance of surficial deposits in Carrington Hill area, Country Conc, Ireland. *Nig. J. Sci.*, 28: 153-158.

Kanawi MA & Kamel AO 2013. Durability of expansive soil treated by chemical additives, *Int. J. Engr. and Innovative Techn.*, 3(1): 315-319.

Lucian C 2006. Geotechnical aspects of buildings on expansive soils in Kibaha'Tazania: Preliminary Study. Division of Soil and Rock Mechanics, Department of Civil and Architectural Engineering, Royal Institute of Technology, Stockholm, Sweden, 150pp.

Malomo S, Olorunniwo MA & Ogunsanwo O 1983. Engineering geological mapping in terrains of tropical weathering - an example from Abuja, Nigeria. *Engineering Geology*, 19: 133-143.

Okogbue CO 1989. Geotechnical and environmental problems of the Niger Delta. *Bull. Engr. Geol. and Envt.*, 27: 119-126.

Okogbue CO & Uma KO 1988. The impact of geology on the performance of a butiminous-surface pavement – A case study from southwestern Nigeria. *J. Afr. Earth Sci.*, 7(1): 257-264.

Oladeji OS & Raheem AA 2002. Soil test for road construction. *J. Sci., Engr. and Techn.*, 9(2): 3971-3981.

Okunade EA 2007. Isopleths of subgrade soil properties for Abia and Imo state of Nigeria. *Int. Res. J. Engr., Sci. and Techn.*, 4(2): 190-205.

Pei-Yaun Chen 1977. Table of keylines in X-ray powder diffraction pattern of minerals in Clay associated rocks. Department of Natural Resources, Geological Survey Occassional Paper 21, 68pp.

Tamhane RV & Namjoshi NC 1959. A comparative study of black soils formed from different parent rocks, *J. Indian Soc. Soil Sci*., 7: 49-68.

Uduji ER, Okagbue CO & Onyeobi TUS 1994. Geotechnical properties of soils derived from the Awgu and Mamu Formations in the Awgu-Okigwe area of southeastern Nigeria and their relations to engineering problems. *J. Mining and Geol.*, 3(1): 117-123.

VenkaraMuthyalu P, Ramu K & Prasada GV 2012. Study on performance of chemically stabilized expansive soil. *Int. J. Advances in Engr. & Techn.*, 2(1): 139-148.