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EFFECT OF MINERALOGICAL COMPOSITION ON THE GEOTECHNICAL PROPERTIES OF CLAY FOUND IN LOKOJA

T.S. AIYEETAN; B.A. ABBAS; & A.M. MUSTAPHA

Department of Civil Engineering, School of Infrastructure, Processing and Engineering Technology, Federal University of Technology Minna, Nigeria.

Abstract

Clay soils are commonly found in various regions around the world and play a significant role in geotechnical engineering projects. This paper aims to investigate the effect of clay soil mineralogy on geotechnical properties. Clay soil samples were collected from three different locations around Lokoja, Kogi State, North Central Nigeria and tests carried out on the samples includes X-ray diffraction analysis (XRD), Specific Gravity, Natural Moisture Content (NMC), index properties (sieve analysis, liquid limit and plastic limit), Universal Compressive Strength (UCS) and California Bearing Ratio (CBR). From the results, the major minerals in each of the three samples are rutile, muscovite and crystobalite respectively, the natural moisture content ranged from 10.8 to 19 percent while the specific gravity of the sample is between 2.48 and 2.55. Test results also showed that the clays have high plasticity index, averaging 19.1%, and a moderate average liquid limit of 38.70%. For the strength properties, the universal compressive strength (UCS) test shows very low values ranging from 242kN/m^2 to 379kN/m^2 and low CBR values indicating that the soils are very poor for pavement cohstruction. The clay minerals have poor geotechnical properties but may possess significant economic values.

Keywords: clay minerals, plasticity, geotechnical, x-ray diffraction

INTRODUCTION

Clays are naturally occurring hydrous alumina-silicates that are products of extensive periods of chemical weathering of primary crystalline rocks. Clay develops plasticity when wet due to the molecular film of water surrounding the clay particles, but becomes hard, brittle, and non-plastic upon drying or firing. Mariam Webster describes clay soil as soil that contains a high percentage of fine particles and colloidal substances and becomes sticky when wet. Among the general characteristics of clay materials include; Clay soils feel very sticky and roll like plasticine when wet possessing a water retention capacity that is higher than any other soil type. Clay can also be described as a type of fine-grained natural soil material containing clay minerals. Clay minerals are ubiquitous components of soil and sediments playing very important functions in geotechnical engineering applications.

Expansive clay is a clay soil that is prone to large volume changes (swells and shrinkage) that are directly related to changes in water content. Generally, this soil type has numerous problems due to its low strength, high compressibility, and high level of volumetric changes.

Marine clay is a type of soil that largely exists in coastal corridors, low lands and offshore areas, and other parts of the earth. It can be described as soft sensitive soil that is always associated with high settlement and high instability, poor soil properties that are not suitable for engineering requirements, uncertainty of performance, low unconfined compressive strength of between 25 to 50 kN/m^{2}. and flat or featureless surface (Ali and Alsamaraee, 2013). Clay needs to be improved before it can be used in constructing roads, dams, slurry Clay existing at the bottom of water bodies and reservoirs such as rivers, harbors, and channels. These are called degraded marine clay and they are usually removed by excavation to enlarge the river channel both in-depth and controlling flooding,,and also create access to the harbor and port channel. The excavated degraded marine clay is disposed of in the environment which ends up as waste (Shahri and Chan, 2015) and waste landfills. Improved gradation, reduction in plasticity and swelling potential, and increase in strength and workability generally improve clay's stability (Nazile, 2018).

Despite the considerable efforts devoted to the study of clay minerals, research is still needed for a comprehensive understanding of the effect minerals contained in clays have on their geotechnical properties which are generally of low strength, high compressibility, high volumetric changes, high plasticity, permeability, bearing capacity and settlement characteristics (Ural, 2018). Clay soils are usually difficult to work on especially marine clay which usually consists of soil minerals such as chlorite, kaolinite, montmorillonite, and illite, and other stone minerals such as quartz and feldspar that are all bonded together by the presence of organic matters (Rahman *et al.*, 2013; Yunus *et al.*, 2015). Adil *et al.* (2021) investigated the effects of clay minerals on soil strength, expressed in terms of California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS), and stiffness, represented by the constrained modulus, which are commonly used as engineering properties for pavement materials. Investigations show that the kaolinite mineral has a more significant effect than the montmorillonite in reducing the plasticity of the clays. Higher strength indicators (CBR and UCS) were observed in samples with high kaolinite content. More so, the kaolinitic soil samples are characterized by a larger constrained modulus (Ec) than in other samples. Also, in the study of Shan *et al.* (2021), the effect of marine clay mineralogy on the dynamic properties of artificial marine clay was investigated using marine clay found in the South China Sea deltas. This study also discovered that the artificial marine clay with high montmorillonite content exhibited slower development of strain, more sluggish growth in pore water pressure, more rounded hysteresis curves, greater stiffness, and more prolonged viscous energy growth than the clay with low montmorillonite content. Lee *et al.* (2016) investigated the marine clay at one construction site in Kedah state, Malaysia, and discovered that the soil has an un-drained shear strength of less than $25kN/m^2$. It is highly challenging to work with marine clay soil due to its great influence on moisture content. It swells when the moisture increases and shrinks when decreases (Pakir *et al.*, 2014). Construction on soft soil has been widely carried out in several countries, especially in coastal areas. Most of the soft soils found in these construction projects have been improved by vertical drains and surcharge preloading methods. A comprehensive review of the literature indicates that a considerable amount of work related to the determination of the engineering behavior of clay soils has been carried out worldwide over the last 50 years. Amongst various contributions, the investigations on physical, chemical, and mineralogical properties of marine clay conducted by Eden *et al.* (1957), Noorani (1984), Shridharan et al. (1989), Mathew et al. (1997) and Chew *et al.* (2004) are worthy of note. Significant research on strength and stiffness characteristics was performed by Koutsoftas *et al.* (1987) and Zhou *et al.* (2005). In various other countries, detailed geological and geotechnical engineering characterizations of clays have been undertaken. However, there is still limited understanding of the effect of mineralogical properties of clay found in the Lokoja basin in Nigeria, as an investigation into this location has not been previously reported. This research aims to address the effects of the mineralogical composition of clay (found in Lokoja) on the geotechnical properties. To achieve this aim, the research is designed to achieve the following set objectives to determine:

i. mineralogical composition of clay samples from selected locations within the Niger River basin in Lokoja, Nigeria.
ii. the physical properties such as moisture content, sieve analysis, specific gravity, and Atterberg limit tests of the clay samples
iii. the geotechnical properties affected by the constituent clay minerals.

Justification

Clay mineral analysis of soils is unfortunately, not usually employed in the routine examination of soils for engineering projects. This is partly because the techniques and equipment are beyond the resources of the ordinary soil testing laboratory (Alhassan *et al.*,2012). The need for proper understanding of the engineering geology, the mineralogical properties, and the compressibility of clay as well as detailed characterization of clay obtainable from Lokoja basin so as to provide literature on the study location and as well provide uses of clay that will withstand ecological and environmental challenges like perennial flood.

Scope of the Study

The scope of this study encompasses a comprehensive investigation into the effects of the mineralogy of clay on geotechnical properties. It aims to provide valuable insights and practical guidelines for geotechnical engineers involved in the design and construction of infrastructure projects involving clayey soils. The study focuses on the following aspects:

1. Clay Mineral Identification: The study will involve the identification and classification of clay minerals present in clayey soil samples obtained from various geological formations. Technique such as X-ray diffraction (XRD).
2. Geotechnical Properties Characterization: The geotechnical properties of the clayey soil samples were characterized through a series of laboratory tests. These tests include: direct shear tests, and unconfined compression tests. The objective is to obtain data on geotechnical parameters such as shear strength, the California bearing ratio (CBR) values of the samples.
3. Analysis of test results: The data obtained from laboratory tests was analyzed to establish a relationship between clay mineralogy and geotechnical properties.

It is important to note that the study's scope is focused on the effects of clay mineralogy on geotechnical properties, specifically related to strength, compressibility, permeability, and shear behavior. The study may not extensively cover other geotechnical properties such as swelling potential, shrinkage behavior, and erosion susceptibility. Additionally, while efforts will be made to validate the models and relationships using field data, the availability of comprehensive field data may be limited.

METHODOLOGY

Materials and Methods.

Materials

The material used for this research work is clay which was sourced from test pits around Lokoja, Kogi State North central region of Nigeria.

Methods

Physical and mineralogical test

The following tests were carried out on clay; all tests were carried out at the Geotechnics laboratory of the Federal University of Technology Minna. Physical and geotechnical properties such as natural moisture content, specific gravity, sieve analysis, Atterberg's limit, California bearing ratio (CBR) and unconfined compressive strength (UCS) tests were carried out in accordance to BS 1377 specifications while the mineral composition of the soil (XRD) test was conducted in a laboratory outside the state

X - Ray Diffraction Analysis

This test was carried out to determine the clay minerals present in the samples. Automated x-ray diffractometer was used. It is made up three main components or parts:

i) The diffractometer;

ii) The computer system and

iii) Coolers, for cooling the diffractometer.

The sample were pulverized and sieved through 75 μm sieve size. In this test three stages were involved:

Natural Moisture Content

The test procedures conducted on the clay samples collected were as follows: the weight of the moisture cans was recorded; the clay samples as obtained from pits at different depth at different locations was recorded and weighed as wet clay + can.; the weight of wet clay + can was then placed in the oven for 24hours at 105 degrees. Water content W, the difference between the weight of wet soil + can and the weight of dry soil + can which is the weight of the W_w of the clay samples was noted and recorded.

Specific Gravity

A specific gravity test was conducted on the clay samples in the laboratory. The volumetric flask was first weighed; a quantity of clay samples was poured into the flask; the clay samples as contained in the volumetric flask were weighed together and recorded; little quantity of water was added to the clay sample in the flask for about 10 minutes to dissolve the sample completely; more water was added to fill up the flask then the weight of the soil, water and cylinder was noted and recorded; the process was repeated for all the samples for this research work.

Sieve Analysis

Clay samples as obtained from the pit in Lokoja was placed on No 200 sieve and the sample materials was carefully washed through the sieve using tap water until the water is clear; the residue was carefully poured into a large weighed dish for a short period of time until the top suspension became clear; the mixture contain the clean top water and the dish with the remaining soil-water suspension was placed in the oven for drying at 105^{0}C for 24 hours; after 24hours, the oven dry residue was weighed and recorded; the sieve with the content varying from larger to smaller size from top down was noted and recorded; the stack of sieve was placed in a sieve shaker for 5 to 10miniutes;the stack of sieve was removed from the shaker and weight of materials remaining in each sieve aperture was noted and recorded ;percentage retained on each sieve by dividing the weight retained on each sieve by the original clay sample weight was noted; percentage finer starting with 100% by subtracting the percentage retained on each sieve as cumulative procedure was computed and recorded (%passing =100-%retained) . The steps were repeated for clay samples for this research work.

Atterberg Limit (liquid limit, plastic limit, and plasticity index)
Liquid limit test (using Casagrande Device)
Clay samples obtained from the pits in Lokoja were test run for the Atterberg limit test. The clay samples were air dried for some hours; a pestle and mallet were used to break the lumps of soil before sieving; sieving of clay samples was done carefully;200g of clay sample was placed in a mixing dish, with the addition of a small quantity of water; the mixture was done with a spatula to have a uniform colour. When the soil became consistent (stickiness); the soil was given 50 blows to close the standard grove of 12.7mm. About 20g of the thoroughly mixed soil from the dish was removed for the plastic deformation; a small amount of the soil was in the brass cup of the Casagrande device to correct the depth of the grooving tool; the surface of the clay sample pat was smoothened carefully using the grooving tool, a clean straight groove was cut to separates the clay sample pat into two parts; by smoothening the surface of the soil, the depth was trimmed with the shoulders of the tool at the deepest part; after making the groove, the blow was count using the turner to blow the clay sample inside the Casagrande cup. The material stopped turning when the clay joined at the middle; the counter was read to record the number of blows; a spatula was used to get the middle part of the soil; the clay sample pit in a can was weighed; the weight of the soil and the can was immediately placed in an oven preheated to 105^{0}C for 24hours.

Plastic Limit
The clay samples of 20 to 30g 'peanut' set aside earlier were broken into several smaller sizes; the wet clay sample was rolled with the palm with hand on the glass plate/board; the sample was rolled into thread uniform diameter until the diameter reaches 3.2mm crack stage; the weight of the can and weight of soil at this stage was

noted; the soil was placed to dry for 24hours; the weight after dryness was also noted and recorded.

Plasticity index

Plasticity index on clay sample as recorded = Liquid limit – Plastic Limit (PL= LL-PL)

Compaction Test

3kg of air-dried clay sample passing through a 20mm BS sieve was weighed and mixed thoroughly with water (6% by mass of sample) coupled with an empty mold with the base plate attached. The compaction mold was then fixed with the base plate and the collar, filled with a soil sample, and compacted into three equal quantities per layer. Each layer was given 27 blows of the free-falling rammer. The compacted clay sample was leveled with a spatula and the weight of the mold with soil was recorded The samples taken from the top and base were placed in a can was placed in an oven. These samples were used to determine the moisture content of the sample. The soil broken up was mixed with more water to give a higher moisture content of about 3% after compaction. The whole procedure was repeated until the mass of soil with mold began to decrease. The bulk density of the soil was then obtained as $P_b = (M_2-M_1)/1000$. While the dry density of the sample was obtained as $Pd = P_b/(1+ w)$. Where w = moisture content. The graph of dry density and moisture content was plotted and the approximate maximum value of dry density and relative optimum moisture content was obtained for the clay samples.

CBR test

CBR test was conducted for soaked and unsoaked using the clay samples

For unsoaked Specimen

The clay sample was sieved through a 20mm sieve 4.5kg and 5.5kg for fine-grained and granular soils were mixed in a tray. Water was added to the sample in quantity such that the moisture content of the specimen is either equal to field moisture content or OMC as desired. The sample was mixed for water uniformity. The mold was clamped along with an extension collar to the plate, after which the coarse filter paper was placed on top of the spacer disc. The mixed soil water was poured into the mold such that a quantity after compaction was about 1/5 of the mold filled. The layers of given a required number of blows with the rammer in layers. The top of the layer of the compacted surface was scratched, more soil was added and compacted similarly, and then the mold was filled in five layers. Excess soil was trimmed off after the removal of the extension collar. The base plate, spacer disc, and filter paper were removed and the weight of the mold and compacted specimen was noted. The coarse filter paper was placed on the perforated base plate. The inverted mold containing the compacted soil was clamped to the base plate.

For Soaked Specimen

The clay sample excluding the base plate and spacer disc was weighed. A filter paper was placed on the sample with a perforated plate on it. A surcharge weight of 2.5kg or 5kg was placed and the sample was soaked in the water tank for 48 hours. The sample was then allowed to drain off water in a vertical position for about 15-20minutes. The sample was weighed again to determine the percentage of water absorbed. It was then tested following normal procedure.

Results and Discussion

Index properties of the soils

The results of the index properties of the soils, shown in table 4.1, indicate the LL values of the soils ranging between 34.1 to 43 %. The Plasticity Index (Ip) of the tested soil samples ranges between 16 to 22%. The plasticity of samples 1, 2, 3 indicates that their clay fractions are of high plasticity according to Unified Soil Classification System (USCS) (ASTM. 1970). These results agree with earlier findings by (Alhassan, 2006) and (Mustapha and Alhassan., 2012). The XRD result of the samples shows different major minerals in each of the samples ranging from rutile, muscovite and cristobalite but also the presence of quartz in samples 2 and 3 as shown in figures 4.1,4.2 and 4.3. These minerals have high affinity for water which is responsible for the high plasticity.

Table 4.1: Summary of physical properties of the studied soil sample

	Properties						
Sample	Natural Moisture Content (%)	Specific Gravity	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	USCS Classification	AASHTO Classification
1	19	2.48	43	21.0	22	CH	A-7-5
2	19	2.52	34.1	18.3	16	CH	A-7-5
3	10.8	2.55	38.9	19.6	19.5	CH	A-7-5

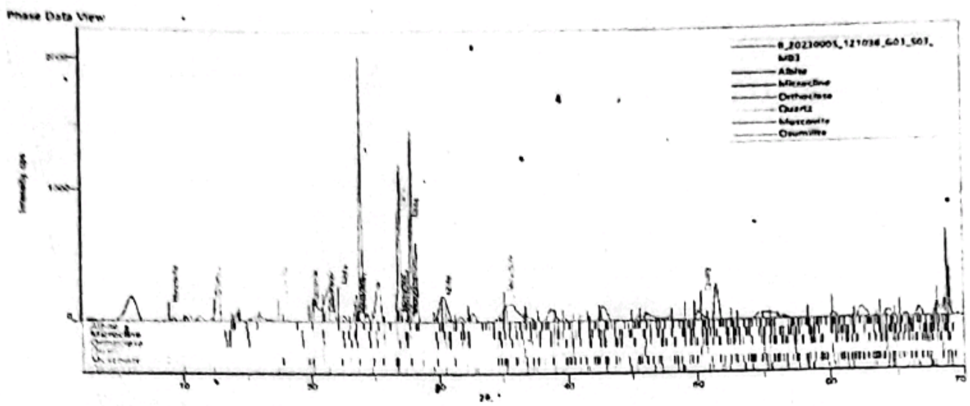

Figure 4.1: XRD result for soil sample1

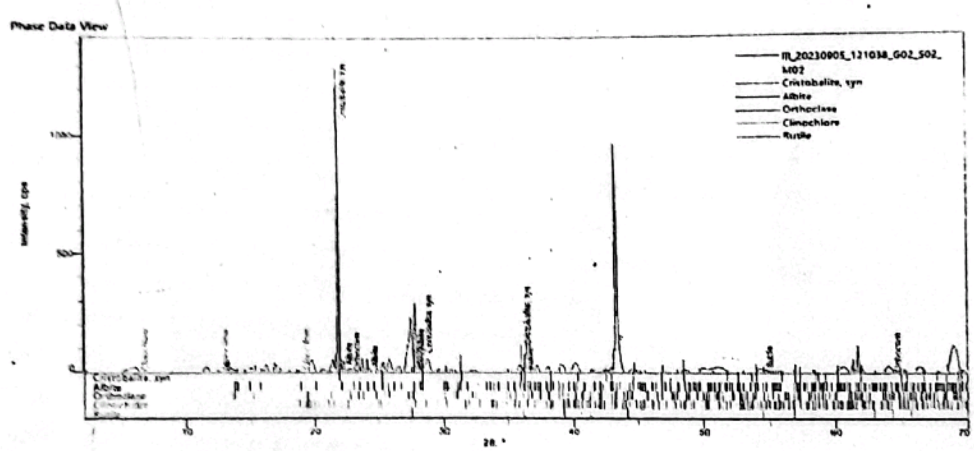

Figure 4.2: XRD result of soil sample 2

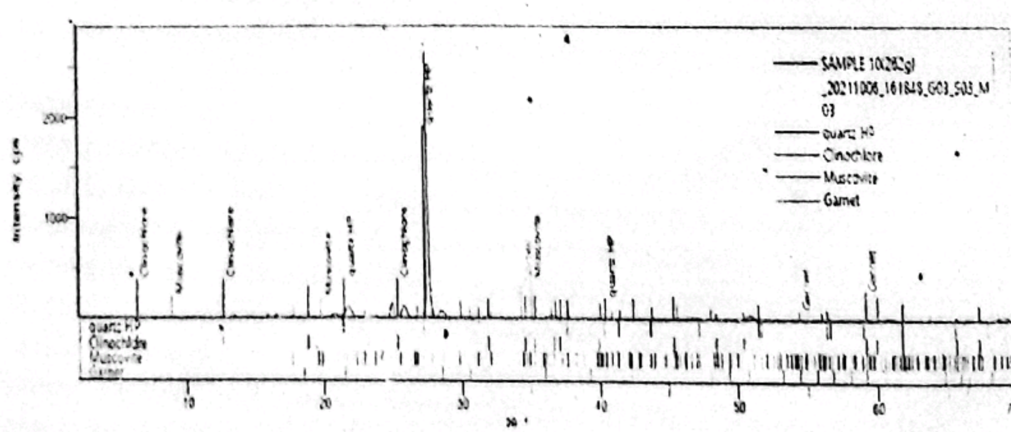

Figure 4.3: XRD result for soil sample 3

CONCLUSION

One of the key findings in this study is that the presence of cristobalite, rutile and muscovite expansive clay minerals, contributes to the clay's high plasticity and cohesion. This characteristic makes Lokoja clay unsuitable for certain construction activities, such as embankments and foundations, where low settlement and stability are essential.

The presence of montmorillonite and illite, both expansive clay minerals, can lead to significant volume changes with changes in moisture content. This expansive behavior can result in swelling and shrinkage, which may pose challenges for engineering projects if not properly managed. Therefore, it is essential to consider these mineralogical factors when designing structures or foundations on Lokoja clay to mitigate potential issues related to soil movement.

Furthermore, the mineralogical composition also affects the permeability of clay found in Lokoja. The presence of specific minerals may lead to variations in hydraulic conductivity, which can impact the drainage and seepage characteristics of the clay. Engineers should account for these variations when designing drainage systems or assessing the suitability of Lokoja clay for specific applications.

In summary, understanding the mineralogical composition of Lokoja clay is crucial for making informed decisions in geotechnical engineering projects. Engineers and geologists should conduct thorough mineralogical analyses to tailor their designs and construction techniques to the specific properties of these clay materials, taking into consideration its plasticity, cohesion, expansiveness, and permeability. By doing so, they can ensure the successful and safe execution of projects involving Lokoja clay, ultimately contributing to the sustainable development of infrastructure in the region.

RECOMMENDATIONS

- **Comprehensive Mineralogical Analysis:** Conduct an in-depth mineralogical analysis of Lokoja clay, including identifying the types and percentages of minerals present. This can involve techniques such as X-ray diffraction (XRD) and scanning electron microscopy (SEM). A detailed understanding of the mineralogical composition is essential to establish correlations with geotechnical properties.
- **Laboratory Testing with Varied Mineral Ratios:** Perform laboratory geotechnical tests on Lokoja clay samples with controlled variations in mineral ratios. By systematically altering the mineral composition and conducting tests like triaxial shear tests, consolidation tests, and permeability tests, researchers can quantify the direct impact of mineralogical changes on geotechnical properties.

- **Environmental Influence Study**: Investigate how environmental factors, such as temperature and moisture content, affect the geotechnical properties of Lokoja clay with different mineral compositions. This would help in understanding how seasonal variations and climate change might impact engineering projects built on this clay.
- **Long-Term Performance Analysis**: Conduct long-term monitoring and analysis of engineering structures (e.g., foundations, embankments) built on clay found in Lokoja with varying mineralogical compositions. By observing their behavior over time, researchers can conclude the stability and durability of these structures under real-world conditions.
- **Geotechnical Engineering Guidelines**: Develop geotechnical engineering guidelines and recommendations specific to clay found around the city based on its mineralogical composition. These guidelines can assist engineers and construction professionals in making informed decisions regarding the selection of suitable foundation designs, construction techniques, and soil stabilization methods.

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