IKR Publishers

IKR Journal of Engineering and Technology (IKRJET)
Journal homepage: https://ikrpublishers.com/ikrjet/
Volume-2, Issue-6 (November-December) 2026
OPEN ACCESS
ISSN: 3107-7331 (Online)

# Geotechnical Evaluation of Some Selected Clay Samples Southwestern Nigeria: Implications for Industrial Use

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***DOI:*** *10.5281/zenodo.24104135*

**ARTICLE INFO**

***Article history:***
***Received : 22-10-2026***
***Accepted : 02-11-2026***
***Available online : 10-11-2026***

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**Citation:** Ihogbetin, F. F., Olatunji, J. A., Babalola, S. A., & Alhassan, A. O. (2026). Geotechnical Evaluation of Some Selected Clay Samples Southwestern Nigeria: Implications for Industrial Use. *IKR Journal of Engineering and Technology (IKRJET), 2*(6), 23-31.

**ABSTRACT** **Original Research Article**

Clay soils pose significant challenges in geotechnical engineering due to their complex behaviour, which is very sensitive to moisture changes and environmental conditions; understanding their properties makes it easier to determine their areas of application. This paper provides a comprehensive review of clay evaluation by integrating its physical, microstructural and engineering classifications. Four clay samples taken from Ajase-Ipo and Isan-Ekiti in Southwestern Nigeria were subjected to geotechnical tests; parameters assessed include particle size distribution, Atterberg limits, porosity, and water absorption. The grain size analysis classified the samples as fine-grained, which was confirmed by the Atterberg limit test, which recorded the plastic limit to be in the range of 19.8% to 28.0% and a high plastic index of 27.3% to 30.6%, indicating high swelling capacity. The physical properties of the four samples show standard engineering classifications. It was concluded that the four clay samples are suitable raw materials in manufacturing industries and not very suitable for use in construction.

**Keywords:** Clay Mineralogy, Microstructural Analysis, Engineering Classification, Plasticity, Geotechnical Stability.

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## Introduction

Clay is a soft, freely bound, fine-grained natural earthy material having a diameter less than 0.005mm, they exhibit plasticity in the presence of water and becomes hard on drying and firing. From the standard definition of minerals, clays are mainly inorganic materials that contain a huge amount of organic or natural materials [1]. Clay deposit and clay minerals are particularly important industrial materials because they are used in the manufacturing of various household items ranging from ceramic products, cement, sanitary ware, manufacturing of drugs to catalysts in the pharmaceutical industry. Clay minerals also find application in nanotechnology for the manufacturing of crystals. Kaolin, a type of clay is used in glossy paper for high quality prints. Kaolin is also used in paint manufacturing, as impact strength and fillers in plastics, and in the production of enamel [2].

Plasticity, grain size distribution and the mineral composition define the quality and properties of the end product of clay. The variation in mineralogical and engineering properties of clays depends on the make-up of the parent rock, topography, climate, vegetation, length of

weathering and other factors indicated that the mineralogical composition of soil is responsible for all the engineering properties such as specific gravity, shear strength, Atterberg limits, petro-physical properties and soil classification. Since the mineral composition and texture of pre-existing rocks determine the characteristics of the soil which are all a function of the types of soils and their grain size distribution [3].

Clay minerals are considered as gift for human beings as they are exploring the clay minerals continuously through research as these are of very low cost, environment friendly, easily available and non – toxic. The clay minerals are so widespread that in the world, there is hardly any country where there are no deposits of one or other kind of clay minerals. In nature, clay minerals are found with certain physical and chemical characteristics due to which these clay minerals play an important role in different fields from research to industries [1]. Clay minerals share a basic set of structural and chemical characteristic and yet each clay mineral has its own unique set of properties that determine how it will interact with other chemical species. The variation in both chemistry and structure, among the clays leads to their applications in extremely diverse fields. The specific clay minerals are identified by several techniques including thermal differential analysis, scanning electron microscope, infrared spectrometry and X-ray diffraction. Chemical analysis is an essential step to establish the nature of minerals [4]. In geotechnical engineering, it is important to identify a clay type, as the type directly affects the important properties of clay, such as Atterberg's limits, hydraulic conductivity, swelling-shrinkage, settlement (compression) and shear resistance. Atterberg's limits, known as consistency limits, define the relationship between ground particles and water and the state of the soil relative to varying water contents. With increasing moisture content, clay changes from solid state, to semisolid state, to plastic state and to liquid state [5]. Clay minerals are classified into different groups as follows; Kaolinite, Smectite, Vermiculite, Illite and Chlorites. Kaolinite is the purest of all clays, with little variation in composition. It also does not absorb water or expand when it comes into touch with it. As a result, kaolinite $Al_2Si_2O_5(OH)_2$ is the ceramic industry's chosen clay.

Studies have shown that many natural resources in Nigeria, especially clay, have not received sufficient attention; hence the need to explore Nigeria's rich local clay deposits and their industrial/relevant applications. It is common practice to assess materials like clay for suitability by considering their specific and general properties for design and construction purposes [6]. For materials to be made good use of their properties must be well understood. Reliable information on material characteristics can be obtained from physical and mechanical tests, aiding in their optimal and appropriate application. Geotechnical investigation of clay soil is crucial before constructing any structure, as the load of the structure is eventually transferred to the underlying soil. Therefore, understanding the geotechnical properties of clay soils is essential for determining their industrial applications. This study aims to make information available for the use of clays from Ajase-Ipo area in Kwara State and Isan-Ekiti area in Ekiti State, Southwestern Nigeria, with a focus on determining their suitability in industries.

## Materials and Methods

The research was executed in two phases: field collection and laboratory analysis. During the fieldwork phase, two clay samples each were gathered from abandoned pits in Ajase-Ipo, Kwara State (08°13'60''N, 04°49'03''E) and Isan-Ekiti, Ekiti State (07°56'45.30''N, 05°19'58''E). The second phase involved geotechnical testing of these samples.

### Grain Size Analysis

Grain size analysis which quantifies the particle diameters, their relative proportions, and overall distribution of constituents within a soil matrix can be achieved in two ways. Mechanical Sieve Analysis used to determine the distribution curve for coarser particulate fractions while Hydrometer Analysis gives the precise percentages of the finest fractions (silt and clay) using sedimentation behaviour.

**Mechanical Sieve Analysis -** This test quantifies the particle-size distribution of coarser soil fractions by agitating the sample through a vertical stack of progressively finer mesh screens.

Apparatus: Stack of standard sieves & collecting pan, Mechanical sieve shaker & cleaning brush, drying oven & weighing balance.

### Laboratory Procedure

Disaggregation: Gently break up dry clay aggregates into individual grains.

a. Sieve Setup: Arrange the sieve stack in descending order of aperture size, placing the collecting pan at the base.
b. Loading: Weigh a 100g representative soil sample and pour it onto the topmost sieve.
c. Agitation: Secure the stack in the mechanical shaker and agitate for approximately 10 minutes.
d. Weighing: Disassemble the stack and weigh the mass of soil retained on each sieve.
e. Data Processing: Convert the mass data into cumulative percentages passing on each sieve.
f. Data Interpretation: The cumulative percentage of fines is plotted against the sieve aperture size on a semi-logarithmic graph to construct the particle-size distribution curve. The grading and slope characteristics of the soil are evaluated using critical geometric parameters: Effective Size (D10): The grain diameter at which 10% of the soil mass is finer. Coefficient of Uniformity (Cu): Measures the slope and range of the particle distribution. Coefficient of Curvature (Cc):

Assesses the smooth shape and continuous gradient of the grading curve.

## Hydrometer Analysis

This sedimentation-based method determines the grain-size distribution of fine-grained soils (silt and clay fractions). The analysis is applicable only if more than 10% of the total soil sample passes through a 0.075mm (No. 200) mesh sieve.

**Apparatus:** Standard hydrometer bulb and 1L glass measuring cylinder, Thermometer and evaporating dish and a Drying oven.

## Laboratory Procedure

a. **Collection:** Gather the fine clay and silt fractions passing through the washing sieve into a settling container.
b. **Drying:** Decant the clear supernatant water and oven-dry the remaining mud residue for 24 hours.
c. **Suspension Preparation:** Pulverize the dry residue, weigh a 50 g sample, and mix it into a 1L measuring cylinder filled with water. Add sodium hexametaphosphate as a deflocculating agent to prevent particle clumping and ensure discrete settlement.
d. **Measurement:** Insert the hydrometer bulb into the suspension and record periodic density readings as the bulb sinks over time.
e. **Thermal Correction:** Measure and record the suspension temperature at every hydrometer reading interval to correct for fluid viscosity changes.
f. **Grading Plot:** Convert the time-density logs into equivalent particle diameters to plot the cumulative percentage passing versus grain diameter, yielding the fine-fraction composition.

## Atterberg Test

The Atterberg Limit test, also known as the consistency limit test, was performed using the Casagrande method to determine how moisture content influences fine-grained soil. This testing process defines the distinct boundaries of a plastic soil's consistency states to evaluate both plasticity and clay content. Specific parameters established through this method include the liquid limit, plastic limit, plasticity index, liquidity index, and relative consistency.

## Porosity

Porosity is the percentage of a soil sample's total volume that consists of empty spaces (voids). This property determines the ground's fluid storage capacity, its settlement behavior under structural loads, and its water flow permeability.

## Experimental Procedure

a. Preparation and Drying: Clay samples were molded into 25 cm × 25 cm cubes and oven-dried at 105 °C until their weight stabilized to a constant dry mass (Wd).
b. Cooling & Saturation: The dried specimens were cooled in a desiccator for 30 minutes, completely submerged in water for 24 hours, and weighed to obtain the wet mass (Ww).
c. Calculation: Porosity (n) was computed by finding the mass of water absorbed by the pores (Ww - Wd), dividing it by the total specimen volume (V), and converting it to a percentage using the formula:

$$n = \frac{Ww - Wd}{V} \times 100$$

## Water Absorption Capacity Procedure (ASTM C97)

a. **Submersion:** Submerge the clay specimens completely in water for 24 hours.
b. **Wet Weighing:** Weigh the saturated samples to record their wet mass (Ww).
c. **Drying:** Wipe the sample surfaces, air-dry them, and weigh them to find the dry mass (Wd).
d. **Calculation:** Compute the water absorption capacity percentage (Wsw) using the formula:

$$Wsw = \frac{Ww-Wd}{Wd} \times 100$$

**Bulk Density:** Bulk density is defined as the mass of the clay divided by its volume; it is the weight of the representative wet clay sample to the volume of the mould containing such a sample. It is expressed as mass per unit volume (i.e., g/cm$^3$). It helps to determine how heavy the clay sample is.

**Apparatus Used includes:** Mould, weighing balance, drying oven, Spatula and pestle.

### Procedure

a. An empty mould is weighed (i.e., weight of mould).
b. The volume of the mould was also determined (V).
c. The mould is then filled with fresh clay sample, consolidated and weighed (i.e., weight of mould + soil).
d. The weight of the wet soil was calculated by subtracting the weight of the empty mould from the weight of the wet soil and mould (w).
e. The bulk density was deduced using the formula below:
$\gamma = \frac{W}{V}$
W = weight of representative wet soil sample
V = volume of mould

## Determination of Linear Shrinkage

Linear shrinkage is the change in dimension of a soil sample when dried from its liquid limit to an oven-dried state. It determines a soil's shrink-swell potential, and this helps to identify highly expansive clays that can crack foundations and damage pavements.

### Procedure used

a. The clay sample was thoroughly mixed with distilled water.
b. A linear container of known length was taken and lubricated for easy removal of the clay sample after moulding.

c. The container was then filled with the clay sample, and its original length (L1) was measured before it was oven-dried for about 24 hours.
d. The container was allowed to cool in a desiccator, and then the final length (L2) of the dried clay sample was measured.
e. The linear shrinkage (LS) of the studied soil samples was calculated using the formula below:

$$LS = \frac{L1}{L2} X\ 100$$

# Results and Discussion

## Particle size analysis

The particle size analysis of materials will synthesize the results of the mechanical sieve analysis, hydrometer settling metrics, and the grain size distribution for the samples studied from Ajase-Ipo and Isan-Ekiti. The particle size curve is extremely useful in soil classification in terms of understanding compressibility because uniform soils are more compressible than well-graded soils [7].

The clay materials are composed of fine-grained particles with complete absence of coarse fragments, as noted on Tables 1a through d. Sand fractions are small in quantity ranging from maximum 19% in Ajase-Ipo 1 to minimum 13% in Isan-Ekiti 2. It can be noted also from the Tables (1a-d) that roughly about 80% to 87% of the total mass passes through the finest standard mesh falling into the pan. Total fines (%fines) ranges from 81% in Ajase-Ipo1 to 87% in Isan-Ekiti 2. Because the initial mechanical sieve analysis revealed a significant fraction of fine particles across all four soil samples, a subsequent hydrometer analysis was required to accurately characterize the fine-grained matrix. The resulting sedimentation data for each sample are detailed in Tables 2 through 5. To visualize the complete particle size distribution and overall grading characteristics of the clay samples, the combined data points are plotted on the semi-logarithmic graph shown in Figure 1.

**Table 1a.** Mechanical Sieve Analysis for Sample Ajase-Ipo 1.

| Sieve size (mm) | Wt. retained (g) | % retained | % passing | | Cumulative % Retained |
|---|---|---|---|---|---|
| 2.36 | 0.0 | 0.0 | 100.0 | | 0.00 |
| 2.00 | 0.0 | 0.0 | 100.0 | | 0.00 |
| 1.00 | 5.2 | 2.6 | 97.4 | | 2.60 |
| 0.50 | 10.8 | 5.4 | 92.0 | | 8.00 |
| 0.30 | 6.7 | 3.4 | 88.6 | | 11.40 |
| 0.212 | 8.9 | 4.5 | 84.1 | | 15.90 |
| 0.090 | 3.0 | 1.5 | 82.6 | | 17.40 |
| 0.075 | 6.5 | 3.3 | 79.3 | | 20.7 |
| Pan | 157.9 | 79.3 | 0.0 | Total | 76 |
| Total | 199.0 | | | | |

AFS Fineness number = Product/ weight of sample
AFS fineness number = 76/ 100
AFS fineness = 0.760

The low value indicates that the material is extremely fine, which is consistent with the large amount of material 79.3% that passed through all sieves and was collected in the pan.

**Table 1b.** Mechanical Sieve Analysis for Sample Ajase-Ipo 2.

| Sieve size (mm) | Wt. retained (g) | % retained | % passing | | Cumulative % Retained |
|---|---|---|---|---|---|
| 2.36 | 0.0 | 0.0 | 100.0 | | 0.00 |
| 2.00 | 0.0 | 0.0 | 100.0 | | 0.00 |
| 1.00 | 3.8 | 1.9 | 98.1 | | 1.9 |
| 0.50 | 8.9 | 4.5 | 93.6 | | 6.4 |
| 0.30 | 6.7 | 3.4 | 90.2 | | 9.8 |
| 0.212 | 8.7 | 4.4 | 85.8 | | 14.2 |
| 0.090 | 3.7 | 1.9 | 83.9 | | 16.1 |
| 0.075 | 4.9 | 2.5 | 81.4 | | 18.6 |
| Pan | 161.1 | 81.4 | 0.0 | Total | 67.0 |
| Total | 197.8 | | | | |

AFS fineness number = Product/ weight of sample
AFS fineness number = 67/ 100
AFS fineness = 0.67

The fineness modulus of this material is 0.67, indicating an exceptionally fine sand composition.

**Table 1c.** Mechanical Sieve Analysis for Sample Isan-Ekiti 1.

| Sieve size (mm) | Wt. retained (g) | % retained | % passing | | Cumulative % Retained |
|---|---|---|---|---|---|
| 0.50 | 0.0 | 0.0 | 100.0 | | 0.0 |
| 0.30 | 17.9 | 9.0 | 91.0 | | 9.0 |
| 0.212 | 5.0 | 2.5 | 88.5 | | 11.5 |
| 0.150 | 4.6 | 2.3 | 86.2 | | 13.8 |
| 0.090 | 2.1 | 1.1 | 85.1 | | 14.9 |
| 0.075 | 2.6 | 1.3 | 83.8 | | 16.2 |
| Pan | 166.9 | 83.8 | 0.0 | Total | 65.4 |
| Total | 199.1 | | | | |

AFS fineness number = Product/ weight of sample
AFS fineness number = 65.4/ 100
AFS fineness = 0.654

The fineness modulus of this material is 0.23, which signifies an extremely fine, silt/clay material, matching the high hydrometer readings for finer particles below the sieve sizes.

**Table 1d.** Mechanical Sieve Analysis for Sample Isan-Ekiti 2.

| Sieve size (mm) | Wt. retained (g) | % retained | % passing | | Cumulative % Retained |
|---|---|---|---|---|---|
| 0.50 | 0.0 | 0.0 | 100.0 | | 0.0 |
| 0.30 | 0.0 | 0.0 | 100.0 | | 0.0 |
| 0.212 | 6.5 | 3.3 | 96.7 | | 3.3 |
| 0.150 | 11.2 | 5.6 | 91.1 | | 8.0 |
| 0.090 | 3.0 | 1.5 | 89.6 | | 10.4 |
| 0.075 | 4.6 | 2.3 | 87.3 | | 12.7 |
| Pan | 174.6 | 87.3 | 0.0 | Total | 35.3 |
| Total | 199.9 | | | | |

AFS fineness number = Product/ weight of sample
AFS fineness number = 35.3/ 100
AFS fineness = 0.353

The fineness modulus of this material is 0.353, indicating that it consists of extremely fine material.

**Table 2.** Hydrometer Analysis for Sample Ajase-Ipo 1.

| Elapsed time (secs) | Actual hydrometer reading | Hydrometer reading correction (Rh) | Temp$^0$ ($^0$C) | Effective hydrometer depth (L) | K from table | Diameter (mm) | % finer |
|---|---|---|---|---|---|---|---|
| 15 | 1.0841 | 84.1 | 29 | 9.0 | 0.02134 | 0.0165 | 69.5 |
| 30 | 1.0817 | 81.7 | 29 | 9.5 | 0.02134 | 0.0120 | 67.5 |
| 60 | 1.0790 | 79.0 | 29 | 9.7 | 0.02134 | 0.0086 | 65.3 |
| 120 | 1.0754 | 75.4 | 29 | 10.2 | 0.02134 | 0.0062 | 62.3 |
| 240 | 1.0734 | 73.4 | 29 | 10.5 | 0.02134 | 0.0045 | 60.7 |
| 480 | 1.0720 | 72.0 | 29 | 10.7 | 0.02134 | 0.0032 | 59.5 |
| 900 | 1.0692 | 69.2 | 29 | 11.8 | 0.02134 | 0.0024 | 57.2 |
| 1800 | 1.0464 | 46.4 | 29 | 12.4 | 0.02134 | 0.0018 | 38.4 |
| 3600 | 1.0331 | 33.1 | 29 | 13.5 | 0.02134 | 0.0013 | 27.4 |
| 7200 | 1.0230 | 23.0 | 29 | 14.5 | 0.02134 | 0.0010 | 19.0 |
| 14400 | 1.0165 | 16.5 | 29 | 15.2 | 0.02134 | 0.00070 | 13.6 |
| 86400 | 1.0105 | 10.5 | 29 | 16.0 | 0.02134 | 0.00029 | 8.9 |

**Table 3.** Hydrometer Analysis for Sample Ajase-Ipo 2.

| Elapsed time (secs) | Actual hydrometer reading | Hydrometer reading correction (Rh) | Temp$^0$ ($^0$C) | Effective hydrometer depth (L) | K from table | Diameter (mm) | % finer |
|---|---|---|---|---|---|---|---|
| 15 | 1.0799 | 79.9 | 30 | 9.7 | 0.01218 | 0.0098 | 66.4 |
| 30 | 1.0785 | 78.5 | 30 | 9.9 | 0.01218 | 0.0070 | 65.3 |
| 60 | 1.0767 | 76.7 | 30 | 10.1 | 0.01218 | 0.0050 | 63.8 |
| 120 | 1.0748 | 74.8 | 30 | 10.3 | 0.01218 | 0.0036 | 62.2 |
| 240 | 1.0726 | 72.6 | 30 | 10.6 | 0.01218 | 0.0026 | 60.4 |
| 480 | 1.0665 | 66.5 | 30 | 10.9 | 0.01218 | 0.0018 | 55.3 |
| 900 | 1.0487 | 48.7 | 30 | 12.2 | 0.01218 | 0.0014 | 40.5 |
| 1800 | 1.0402 | 40.2 | 30 | 13.0 | 0.01218 | 0.0010 | 33.4 |
| 3600 | 1.0273 | 27.3 | 30 | 14.1 | 0.01218 | 0.00076 | 22.7 |
| 7200 | 1.0127 | 12.7 | 30 | 15.8 | 0.01218 | 0.00057 | 10.6 |
| 14400 | 1.0105 | 10.5 | 30 | 16.3 | 0.01218 | 0.00041 | 8.7 |
| 86400 | 1.0085 | 8.5 | 30 | 18.5 | 0.01218 | 0.00018 | 7.1 |

**Table 4.** Hydrometer Analysis for Sample Isan-Ekiti 1.

| Elapsed time (secs) | Actual hydrometer reading | Hydrometer reading correction (Rh) | Temp$^0$ ($^0$C) | Effective hydrometer depth (L) | K from table | Diameter (mm) | % finer |
|---|---|---|---|---|---|---|---|
| 15 | 1.0773 | 77.3 | 27 | 9.5 | 0.01268 | 0.0101 | 63.9 |
| 30 | 1.0740 | 74.0 | 27 | 10.0 | 0.01268 | 0.0073 | 61.1 |
| 60 | 1.0715 | 71.5 | 27 | 11.2 | 0.01268 | 0.0055 | 59.1 |
| 120 | 1.0694 | 69.4 | 27 | 11.4 | 0.01268 | 0.0039 | 57.3 |
| 240 | 1.0657 | 65.7 | 27 | 11.9 | 0.01268 | 0.0028 | 54.3 |
| 480 | 1.0628 | 62.8 | 27 | 12.1 | 0.01268 | 0.0020 | 51.9 |
| 900 | 1.0433 | 43.3 | 27 | 12.5 | 0.01268 | 0.0015 | 35.8 |
| 1800 | 1.0379 | 37.9 | 27 | 12.7 | 0.01268 | 0.0011 | 31.3 |
| 3600 | 1.0241 | 24.1 | 27 | 13.3 | 0.01268 | 0.00077 | 19.9 |
| 7200 | 1.0179 | 17.9 | 27 | 14.5 | 0.01268 | 0.00057 | 14.8 |
| 14400 | 1.0125 | 12.5 | 27 | 15.2 | 0.01268 | 0.00041 | 10.3 |
| 86400 | 1.0087 | 8.7 | 27 | 16.1 | 0.01268 | 0.00017 | 7.2 |

**Table 5.** Hydrometer Analysis for Sample Isan-Ekiti 2.

| Elapsed time (secs) | Actual hydrometer reading | Hydrometer reading correction (Rh) | Temp$^0$ ($^0$C) | Effective hydrometer depth (L) | K from table | Diameter (mm) | % finer |
|---|---|---|---|---|---|---|---|
| 15 | 1.0863 | 86.3 | 30 | 9.2 | 0.01297 | 0.0100 | 71.0 |
| 30 | 1.0860 | 86.0 | 30 | 9.6 | 0.01297 | 0.0073 | 70.8 |
| 60 | 1.0858 | 85.8 | 30 | 10.0 | 0.01297 | 0.0053 | 70.6 |
| 120 | 1.0824 | 82.4 | 30 | 10.1 | 0.01297 | 0.0038 | 67.8 |
| 240 | 1.0801 | 80.1 | 30 | 10.3 | 0.01297 | 0.0027 | 65.9 |
| 480 | 1.0753 | 75.3 | 30 | 11.0 | 0.01297 | 0.0020 | 62.0 |
| 900 | 1.0635 | 63.5 | 30 | 11.7 | 0.01297 | 0.0015 | 52.2 |
| 1800 | 1.0497 | 49.7 | 30 | 13.0 | 0.01297 | 0.0011 | 40.8 |
| 3600 | 1.0362 | 36.2 | 30 | 14.5 | 0.01297 | 0.00082 | 29.8 |
| 7200 | 1.0201 | 20.1 | 30 | 15.2 | 0.01297 | 0.00060 | 16.5 |
| 14400 | 1.0151 | 15.1 | 30 | 16.1 | 0.01297 | 0.00043 | 12.4 |
| 86400 | 1.0084 | 8.4 | 30 | 16.5 | 0.01297 | 0.00018 | 6.9 |

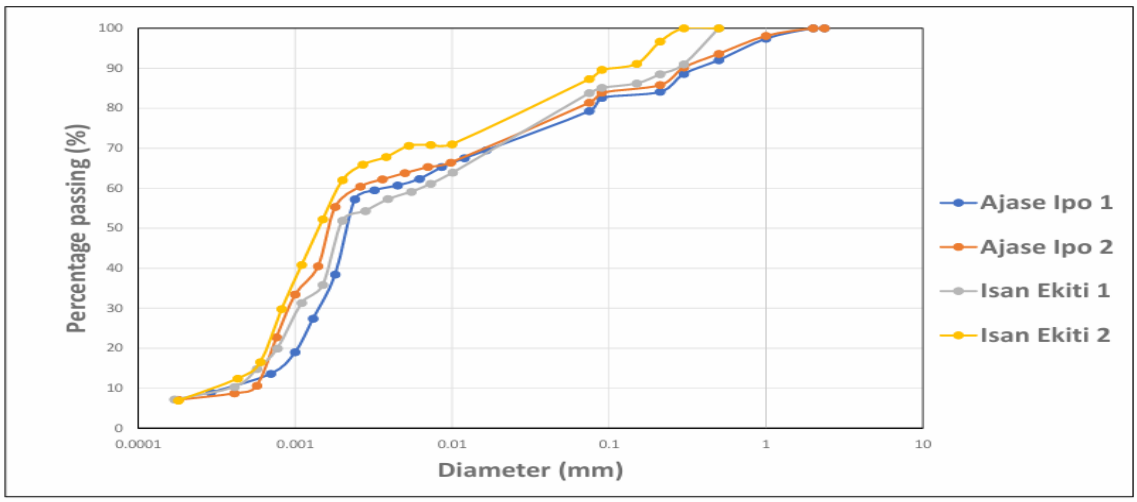



**Figure 1.** Grain Size Distribution Curves for the Investigated Clay Samples

**Table 6.** Summary of Results of Grain Size Analysis of the Studied Clays.

| Sample Name | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | % fine |
|---|---|---|---|---|---|
| Ajase-Ipo 1 | 0 | 19 | 24 | 57 | 81 |
| Ajase-Ipo 2 | 0 | 17 | 23 | 60 | 83 |
| Isan-Ekiti 1 | 0 | 14 | 32 | 54 | 86 |
| Isan-Ekiti 2 | 0 | 13 | 25 | 62 | 87 |

The grain Size Distribution curves in Figure 1 were used to determine the uniformity parameters used to quantify the range, grading and distribution of the particle sizes within the clay soil samples [1]. Table 7 shows the effective diameters ($D_{10}$, $D_{30}$, and $D_{60}$) from the curves and the calculated uniformity parameters.

**Table 7.** Effective Diameters and Uniformity Parameters.

| Sample Name | $D_{10}$ (mm) | $D_{30}$ (mm) | $D_{60}$ (mm) | $C_u = \frac{D_{60}}{D_{10}}$ | $C_c = \left(\frac{D_{30}}{D_{60} X D_{10}}\right)^2$ |
|---|---|---|---|---|---|
| Ajase-Ipo 1 | 0,00036 | 0.00140 | 0.00369 | 10.35 | 1.50 |
| Ajase-Ipo 2 | 0.00051 | 0.00092 | 0.00252 | 4.92 | 0.65 |
| Isan-Ekiti 1 | 0.00038 | 0.00106 | 0.00625 | 16.59 | 0.47 |
| Isan-Ekiti 1 | 0.00029 | 0.00082 | 0.00190 | 6.41 | 1.23 |

Where, $D_{10}$ = Effective diameter, $D_{30}$ = The particle diameter corresponding to 30% passing by weight, $D_{60}$ = The particle diameter corresponding to 60% passing by weight, $C_u$ = The Coefficient of Uniformity measures the overall range of particle sizes present in the soil sample and $C_c$ = The Coefficient of Curvature (also known as the coefficient of gradation) measures the shape and smoothness of the distribution curve between the 10% and 60% marks.

From the data in Table 7, the four samples consist of fine-grained clay soils because their particle diameters are smaller than 0.0075mm. The coefficient of uniformity $C_u$ and the coefficient of curvature $C_c$ values, compared to standard grading parameters (coarse soil $C_u > 6$ and $1 < C_c < 3$; gravel: $C_u > 4$ and $1 < C_c < 3$) [3], gave the following gradings for the clay samples. Ajase-Ipo 1 and Isan-Ekiti 1 clays are both well graded, with wide particle distribution and smooth curves, while Ajase-Ipo 2 and Isan-Ekiti 2 clays are poorly graded with narrow size grades, respectively. The overall diameter range is between 0.00029mm and 0.00625mm positioning these materials as clay to fine silt. A distribution dominated by clay-sized particles suggests that the clay has a higher tendency for agglomeration, as smaller particles are more prone to clumping together [6]. Finer grain size directly increases clay plasticity; similarly, studies have indicated that soils intended for use as barrier materials in landfills should contain at least 30% fines and a clay content of more than 10% [6]. This implies that the clay samples investigated are suitable mainly for industrial use. According to international soil classification standards (USCS and AASHTO) [7], these materials qualify as fine-grained soils because more than 50% of their particles passes the 0.075mm sieve aperture, they are categorized as clays of low-to-high plasticity (CL/CH) or A-6/A-7 silts and clay.

**Table 8.** Summary of Atterberg Limits Test and Plasticity Index of clay.

| Sample name | Liquid limit LL | Plastic limit PL | Plasticity Index PI = LL – PL |
|---|---|---|---|
| Ajase-Ipo 1 | 47.6 | 19.8 | 27.9 |
| Ajase-Ipo 2 | 47.7 | 20.4 | 27.3 |
| Isan-Ekiti 1 | 57.7 | 27.1 | 30.6 |
| Isan-Ekiti 1 | 57.2 | 28.00 | 29.2 |

Atterberg Limits Test and Plasticity Index: The Atterberg limit test determines the moisture content at which fine-grained soils transition between solid, plastic, and liquid states. Atterberg limits give properties that can indicate the amount and type of clay in a sample. They are also essential for understanding the industrial behaviour of clays [6]. From Table 8, the liquid limit values of the samples indicate that they are clays of high compressibility, which corresponds with the particle size analysis. The Shrinkage limits reveal that the soils are fine because the greater the fines, the greater the shrinkage. To confirm if the soil are true geological clays the values of the Atterberg test was cross-reference with Casagrande Standard A-line Equation on the USUC plasticity chart: A-line PI = 0.73 x LL – 20. Ajase-Ipo 1 & 2 have average LL of 47.65 and calculated A-line PI of 20.18 which is lower than their actual PI values of 27.3 and 27.9 and Isan-Ekiti 1 &2 have average LL of 57.45 and calculated A-line PI of27.34 also lower than actual PI values if plotted all falls above the A-line making the materials structurally and chemically true inorganic clays confirming the hydrometer readings.

## Physical Properties

The physical properties data (bulk density, porosity, water absorption, and linear shrinkage) provides the quantitative missing link connecting the particle size distribution (PSD) and Atterberg limits to the raw materials' real-world performance in geotechnical engineering and ceramic/refractory manufacturing.

**Table 9.** Summary of the Physical Properties of the samples.

| Sample | Bulk density | Porosity | Water Absorption | Linear Shrinkage |
|---|---|---|---|---|
| Ajase Ipo 1 | 1.88 | 8.4 | 5.7 | 3.9 |
| Ajase Ipo 2 | 1.81 | 10.1 | 5.1 | 4.6 |
| Isan-Ekiti 1 | 1.75 | 7.5 | 4.4 | 3.5 |
| Isan-Ekiti 2 | 1.67 | 6.3 | 3.5 | 4.1 |

There is an inverse relationship between bulk density, and porosity while a direct relationship is between porosity and water absorption. The higher the bulk density, generally means lower porosity and water absorption.

The data in Table 9, compared with the geotechnical data interpretations, show a distinct separation between the geographical locations of the deposits. Ajase-Ipo 1 and 2 have a silt-quartz skeleton, which makes them exhibit higher bulk density values of 1.88 and 1.81, higher porosity values of 8.4 and 10.1 and high water absorption values of 5.7 and 51. This occurs because the sand and silt fractions are higher making a rigid skeleton with open interconnected packing pores that absorbs water readily but keep the dry soil structurally heavy. Isan-Ekiti 1 and 2 clay possess a packed matrix effect, this is noticeable in the lower bulk density values of 1.75 and 1.67 and very low porosity values of 7.5 and 6.3 respectively. The large clay fraction acts as an ultra-fine structural filler wedging itself tightly inside the void spaces between larger particles, reducing the material's porosity. All four samples have safe linear shrinkage limits under dried baseline conditions; the values fall within the globally accepted industrial maximum for high-quality bricks and tile bodies. Ajase-Ipo 2 exhibits the highest shrinkage and highest porosity; this combination indicates a higher content of fine clay minerals (like kaolinite or smectite) or organic matter that burns off during firing. This makes Ajase Ipo 2 more prone to warping or cracking during drying and firing. Despite having slightly less clay than Isan-Ekiti, Ajase-Ipo 2 experiences the highest overall linear shrinkage (4.6). This matches its higher initial porosity (10.1) and water absorption (5.1). As water escapes the large open capillary pore matrix during drying/firing, the structural walls collapse inward more intensely, accelerating shrinkage.

Isan-Ekiti clays exhibited low water absorption (<5%) and low shrinkage values (3.5% - $.1%), this makes the clay sample highly stable and well-suited for manufacturing structural bricks where dimensional accuracy is critical.

Ajase-Ipo clays possesses higher water absorption values (5.7% - 5.1%) making them not ideal for heavy outdoor construction due to frost and moisture damage risks, their high porosity values of 8.4% and 10.1% make them excellent for use in pottery and lightweight ceramics.

Refractory Advantage: Isan-Ekiti 2 features the lowest structural porosity (6.3) and lowest water absorption (3.5), combined with highly controlled linear shrinkage (4.1). This profile implies a smooth, uniform vitrification process. It makes Isan-Ekiti 2 the most reliable candidate for structural bricks or dense vitrified tiles, as its low water absorption minimizes susceptibility to future environmental frost weathering or moisture damage.

## Conclusion

The physical, microstructural and geotechnical analysis of the four clay deposits from Ajase-Ipo and Isan-Ekiti studied reveals two distinct industrial-grade raw materials. The Ajase-Ipo deposits are classified as Lean clays with their well distributed structural quartz-silt skeleton having high bulk densities and well-developed capillary porosity profiles ideal for general structural pottery and brick-making bodies requiring balanced compaction. Isan-Ekiti deposits classified as fat clays are dominated by fine-grained clay particles which acts as structural pore-fillers, tightly sealing the internal matrix to yield exceptionally low water absorption and low physical porosity. The clay deposit can be used for ceramic and refractory manufacturing as all the samples exhibit highly controlled safe linear shrinkage parameters.

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