

GEOTECHNICAL ASSESSMENT OF CLAY DEPOSIT FROM DIFFERENT LOCATIONS

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ABSTRACT

Clay is formed through the weathering of rocks, often in the presence of water. It's generally composed of micro-crystalline particles of a group of minerals. This project aimed to characterize clay samples which will determine their application in construction. The objective is to determine their physical and mechanical properties. Three clay samples were obtained, two from different location in Omi-Adio, Oyo State and third from Efon-Alaaiye, Ekiti state. Particle size distribution test, moisture content test, specific gravity test, Atterberg limit test, compaction test, California bearing ratio test, direct shear test and consolidation test were performed according to American Society for Testing and Materials (ASTM). First and second clay samples from Omi Adio are brownish red and dark brown in appearance while clay sample from Efon-Alaaiye is cartoon brown by careful visual examination. Brownish red clay is the best in terms of geotechnical properties followed by cartoon brown clay and by dark brown clay. Brownish red clay from Omi-Adio is a stiff clay with the best load bearing capacity and it belongs to the group of kaolinite. Cartoon brown clay is a medium stiff clay and it belongs to kaolinite group with good load bearing capacity while dark brown clay from Efon-Alaaye is a medium stiff clay and its belong to illite group with an average load bearing capacity. The three clay samples can be stabilized with cement, lime, fly ash and fiber reinforcement based on the geotechnical properties but stabilizing brownish red clay will be economical and give the best result.

1. INTRODUCTION

Clay minerals are predominantly phyllosilicate minerals with layered tetrahedral and octahedral structures. Major groups include kaolinite, smectite (including montmorillonite), and illite, while chlorite and vermiculite are other important clay minerals. Their mineralogical composition and structure influence plasticity, permeability, compressibility, shear strength, and volume change. Clay soils are fine-grained and generally exhibit plastic behavior over a range of water contents. Their interaction with water varies considerably among minerals; montmorillonite generally has greater swelling potential than illite and kaolinite (Amiriet al., 2025). Clays are widely used in ceramics, construction, paper production, environmental barriers, and other industrial applications. They form mainly through weathering and alteration of rocks or sedimentary processes and may occur as residual or transported deposits.

Clay deposits are important in engineering applications, including foundations, embankments, road construction, earth dams, and containment barriers. However, their geotechnical properties may vary substantially with geological origin, mineralogical composition, particle-size distribution, moisture condition, density, and location. Inadequate characterization may therefore result in inappropriate design, construction, and maintenance, with associated structural, economic, and environmental consequences. Recent research shows that lateritic clay can exhibit significant swelling, compression, creep, and cracking, emphasizing the need for proper characterization before engineering use (Gao *et al.*, 2024). This study aims to assess the geotechnical properties of clay deposits from different notable locations in southwestern Nigeria and evaluate their potential engineering applications. The findings are expected to provide useful information for engineers, geologists, researchers, and other stakeholders involved in the selection and utilization of locally available clay materials.

Clay materials have relatively low hydraulic conductivity and can therefore serve as hydraulic barriers in applications such as earth dams and landfill containment systems. Their engineering behavior is strongly influenced by mineralogy, water content, density, fabric, and pore-fluid chemistry. Recent research indicates that swelling differs markedly among clay minerals, with montmorillonite showing substantially greater swelling than illite and kaolinite; salinity, pH, temperature, and exchangeable cations can also modify this response (Amiriet *al.*, 2025). Expansive clay can undergo repeated swelling and shrinkage as moisture conditions change, potentially affecting foundations, pavements, slopes, and other infrastructure (Oppong&Kolawole, 2024).

Geotechnical characterization commonly involves particle-size distribution, specific gravity, Atterberg limits, compaction, permeability, and shear-strength tests. These parameters provide essential information for assessing the suitability of clay deposits for engineering purposes. Gao *et al.* (2024) reported that lateritic clay used in tropical and subtropical road construction can exhibit substantial deformation and that its strength is influenced by hydro-mechanical conditions. Similarly, El-Demary (2024) identified initial moisture content, dry density, clay fabric, compaction conditions, mineralogy, surcharge pressure, and degree of saturation as important factors controlling swelling potential.

Where natural clay properties are unsuitable, stabilization may be required. Common methods include mechanical modification and chemical treatment using materials such as lime, cement, and fly ash. Ahmad *et al.* (2024) reported that fly ash can improve the plasticity, strength, penetration resistance, swelling, and compressibility of expansive soils through chemical and pozzolanic reactions. Therefore, comparative assessment of clay deposits from different locations is essential for identifying variations in their engineering properties and determining appropriate uses, treatment requirements, and construction applications.

2. METHODOLOGY

Sieve analysis, specific gravity, moisture content, Atterberg limits, compaction, California bearing ratio (CBR), and direct shear tests were conducted in accordance with ASTM D422, D854, D2216, D4318, D698, D1883, and D3080, respectively. The tests were conducted at the Osun State Ministry of Works Geotechnical Laboratory, Osogbo; Civil Engineering Department Geotechnical Laboratory, Adeleke University, Ede; and Civil Engineering Department Geotechnical Laboratory, Federal Polytechnic Ede. ASTM identifies particle-size distribution, Atterberg limits, compaction and CBR as important procedures for geotechnical characterization.

3. RESULTS AND DISCUSSION

The results of the laboratory tests conducted on the clay samples are presented and discussed below.

3.1 Visual inspection

A careful and thorough visual observation of the clay samples revealed that sample A (clay sample from Omi Adio, Oyo State) is brownish red, clay sample B (clay from Omi-Adio, Oyo State), it to be dark brown clay and clay sample C (clay from Efon-Alaye, Ekiti State) is cartoon brown (Plate 1a to 1c). These colour differences may reflect variations in mineralogical composition, organic matter and iron-oxide content.



A; Sample A



B; Sample B



C; Sample C

Plate 1: Clay Samples

3.2 Sieve analysis test result

Grain-size analysis was conducted to determine the particle-size distribution of the samples. The results are presented in Table 1. Figure 1 presents the gradation curves and the corresponding D_{10} , D_{30} , D_{60} , C_u and C_c values. The reported C_c values fall within 1–3. The samples are predominantly fine-grained. Similar studies of Southwestern Nigerian clay deposits reported predominantly fine-grained materials with considerable variation in plasticity and engineering behaviour (Andre-Obayanjuet *et al.*, 2022; William *et al.*, 2024).

Table 1: Sieve Analysis Test Result for Clay Samples A, B & C

Diameter (mm)	Cumulative Percentage Passing (%) for Sample A	Cumulative Percentage Passing (%) for Sample B	Cumulative Percentage Passing (%) for Sample C
10.00	—	—	—
4.75	—	—	—
2.00	—	—	—
1.18	100	100	100
600 micron	97.9	95.2	98.0
425 micron	94.3	93.1	95.7
300 micron	90.4	90.2	90.4
212 micron	—	—	—
150 micron	84.2	82.4	85.3
75 micron	78.3	78.6	79.3
525 micron	67.7	65.2	67.9
375 micron	49.4	49.3	30.2
200 micron	23.3	22.9	24.3
100 micron	21.6	20.4	20.2
Dust	—	—	—
Total	—	—	—

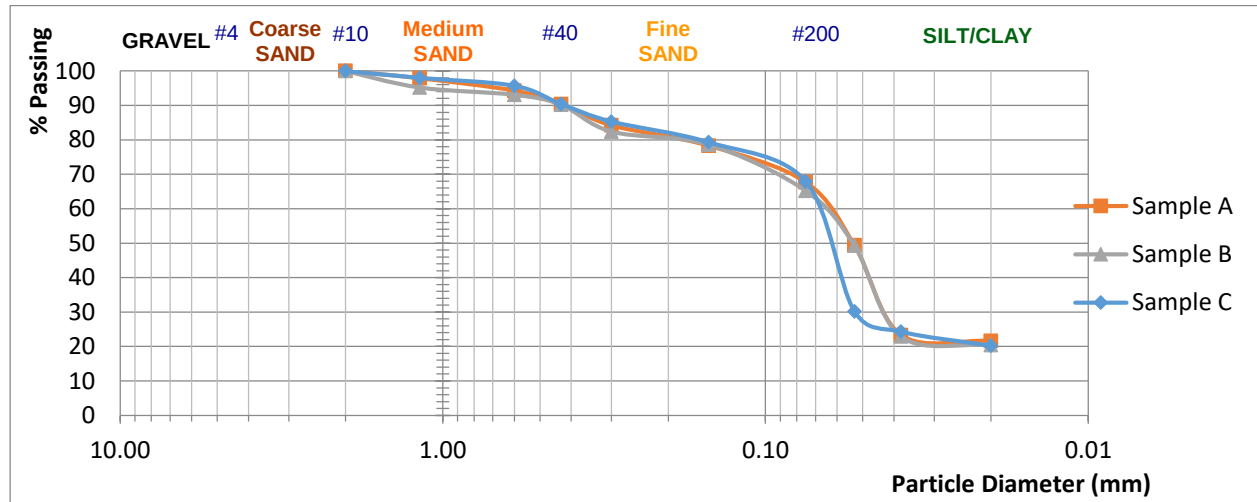


Figure 1: Grain Size Distribution Curve for Burnt Clay

3.3 Specific gravity test

The specific gravity results are presented in Table 2. Sample A has a slightly higher specific gravity than sample B, while samples A and B have approximately 1.14 times the specific gravity reported for sample C. This implies that samples A and B are almost of the same weight and their weight is 12.2% more than that of sample C. Variations may result from differences in mineral composition and organic-matter content. Recent Nigerian clay studies have reported substantial spatial variation in specific gravity, confirming that location can influence the engineering behaviour of clay deposits (Andre-Obayanjuet *al.*, 2022; William *et al.*, 2024).

Table 2: Specific Gravity Test Result for Clay Samples A, B and C

Sample No	Specific Gravity for Clay Sample A	Specific Gravity for Clay Sample B	Specific Gravity for Clay Sample C
1	2.14	2.30	1.85
2	2.40	2.24	2.00
3	2.25	2.36	2.25
4	2.42	2.27	2.00
Average Value	2.30	2.27	2.02

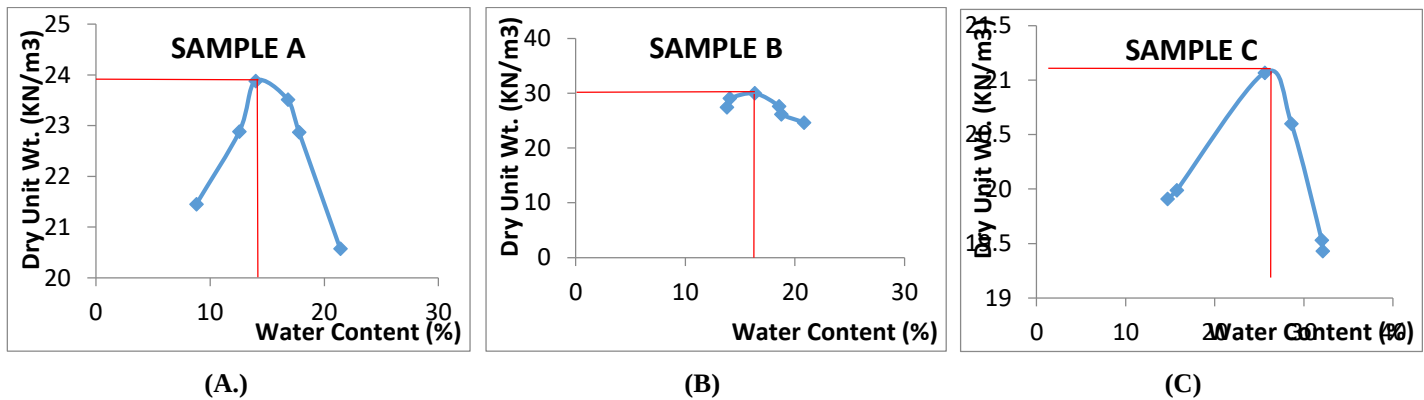
3.4 Compaction test

The results of compaction test are presented in Table 3. From the compaction curve in Figure 2, it can be deduced that the clay sample B, A, and C has maximum dry density (MMD) and optimum moisture content (OMC) 29.99 KN/m³ & 16.34%; 23.88 KN/m³ & 14%; and 21.07KN/m³ & 25.63% respectively. Sample B has the highest value of MMD, follow by A and C. Sample B is MMD is 30% more that of and C which equivalent to about one and a half ($1\frac{1}{2}$) times their values.

The relatively high MDD of sample B indicates a denser compacted state and may partly explain its comparatively better strength performance. Pule and Yendaw (2024) reported that MDD is among the most influential geotechnical parameters affecting CBR, while Nigerian studies have similarly demonstrated substantial variation in MDD and OMC among clay deposits.

Table 3: Compaction Test Result for Sample A, B and C

Sample A: Clay Sample from Omi-Adio, Ibadan			Sample B: Red Clay from Omi-Adio, Ibadan			Sample C: Clay Soil from Efon-AlaaiyeEkiti State		
Moisture Can No.	Water Content	Dry Unit Wt. (KN/m ³)	Moisture Can No.	Water Content	Dry Unit Wt. (KN/m ³)	Moisture Can No.	Water Content	Dry Unit Wt. (KN/m ³)
B1	8.70	21.45	A1	13.33	27.44	C1	17.65	19.91
B2	9.10		A2	14.29		C2	11.76	
B3	12.50	22.88	A3	15.63	29.04	C3	13.85	19.99
B4	13.04		A4	12.50		C4	17.65	
B5	14.30	23.88	A5	17.86	29.99	C5	23.53	21.07
B6	13.69		A6	14.81		C6	27.72	
B7	13.63	23.51	A7	21.31	27.63	C7	28.67	20.60
B8	20.00		A8	15.79		C8	28.57	
B9	17.40	22.87	A9	18.75	26.16	C9	31.90	19.53
B10	18.20		A10	18.75		C10	32.13	
B11	21.10	20.57	A11	20.00	24.65	C11	35.71	19.43
C12	22.72		A12	21.67		C12	28.57	


Figure 2: Compaction Curve for Samples A, B & C

3.5 Atterberg test result

The liquid limit, plastic limit, shrinkage limit, plasticity index, moisture content, liquidity index, activity, consistency index and toughness index are presented in Tables 4a and 4b. Sample C generally records higher consistency-limit and related index values than samples A and B, while sample A exceeds B for most parameters. The results indicate differences in plasticity and moisture sensitivity among the deposits.

Table 4a: Samples A, B and C Characteristics Based on Atterberg Limit Results

Samples Label	Liquid Limit (L.L) %	Plastic Limit (P.L) %	Shrinkage Limit (S.L) %	Plasticity Index (P.I) %	Moisture Content (%)
A	48.00	33.00	4.30	15.00	45.50
B	40.00	27.67	3.25	12.33	31.00
C	50.00	33.00	9.65	17.00	58.30

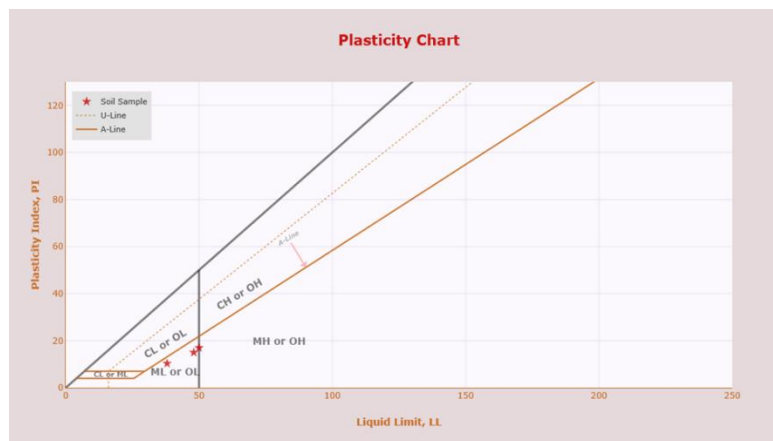
Table 4b: Samples A, B and C Characteristics Based on Atterberg Limit Results

Sample Label	Liquidity Index (L.I) %	Consistency Index (C.I) %	Activity (A)	Flow Index (F.I) %	Toughness Index (T.I) %	Group Index (G.I)
A	0.36	0.64	0.70	1.25	1.36	7.28 ≈ 7.0
B	0.21	0.79	0.41	0.67	1.54	2.80 ≈ 3.0
C	0.44	0.56	1.25	1.63	0.76	10.32 ≈ 10

From Tables 4, the liquid limit, plastic limits, shrinkage limit, plasticity index, moisture content, liquidity index, activity and group index of clay sample C is greater than of samples A and B, and that of sample A is greater than sample B. The consistency index and toughness index of sample.

The soil samples A, B, and C are classified as medium plastic soil base on their plasticity index since their plasticity index values is above 8 but less than 18 (ASTM, 2020; Craig, 2017; Budhu, 2011; Holtz *et al.*, 2011). The plasticity index charts for clay samples A, B, C are presented in Figures 3 and it revealed that the clay samples A, B and C belong to ML or OH that is organic clay or organic silt with low plasticity and low compressibility.

Base on toughness index value, clay C is friable, loose and large-grained in consistency. Clay samples A and B toughness index is greater than 1, the clay can be classified as flexible and pliable clay which means it cannot easily crushed at the plastic limit (Das, 2013; Holtz *et al.*, 2011).

**Figure 3: Graph of Plasticity Versus Liquid Limit for Samples A, B & C**

Flow index is the measure of the rate at which soil mass loses its shear strength with increased water content. Table 4b shows that clay samples A and B can be classified as high flow potential clay while clay B as moderate flow potential clay (Budhu, 2011; Mitchell & Soga, 2005; Holtz *et al.*, 2011). Which implies that C loses its strength by 58.9% and 23.3% above B and A respectively, while sample B loses its strength by 46.4% above sample A. Clay samples A and C are classified as medium stiff clay and may exhibit moderate strength while B is classified as stiff clay and may exhibit high strength base on their consistency index value (Craig, 2004; Das, 2013; Holtz *et al.*, 2011; Mitchel & Soga, 2005). Clay B can be classified as a soil of low liquidity index, its stiff relatively and may exhibit some plasticity, A and C are classified soil in plastic state and may exhibit some plasticity stiff (Das, 2013; Holtz *et al.*, 2011; Mitchel & Soga, 2005; Craig, 2004; Budhu, 2011). The clay can be classified as low activity which is made up of kaolinite or other low-activity clays, medium activity which is made up illite or other

medium-activity clays and high activity which is made up of montmorillonite or other high-activity clays (Skempton, 1953; Das, 2019; Craig, 2004; Mitchell and Soga, 2005; Holtz *et al.*, 2011; Budhu, 2011). From Table 4b clay samples B and A can be classified as normally or moderately active clay which is made up kaolinite while clay sample C is medium activity clay which is made up illite or other medium-activity.

Clay samples A, B, and C are classified into various categories using AASHTO soil classification, S.I soil classification and unified soil classification in Table 5. Samples A & C are classify as A-7-6 soil and B as A-4 soil according AASHTO. Sample A and C have poor subgrade quality while sample C has fair subgrade quality. Samples A and C is classified as CL while sample C is classify as ML & OL according to S.I soil classification which mean samples A and B is inorganic clay of low compressibility while sample B is inorganic and organic silt with low compressibility. According to unified soil classification samples A and B is as CL, inorganic clay with low compressibility, plot on or above the A-line while sample C is classify as MH or CH organic silt or organic clay with high compressibility.

Table 5: Classification of Clay Samples

Sample Label			
A	A – 7 Since P.I < 30 A – 7 - 6 Poor subgrade quality	CL, inorganic clay of low compressibility.	Inorganic, plots on or above the A-line, CL organic clay with low compressibility.
B	A – 4 Silty Soil	ML & OL inorganic and organic silt low compressibility.	Plots on or above the A-line, CL organic, organic clay with low compressibility.
C	A -7 Since P.I < 30 A – 7 -6 Poor subgrade quality	CL,inorganic clay of low compressibility.	MH or CH organic silt or organic clay with high Compressibility

3.6 Direct shear strength

The direct shear results are presented in Table 6. Based on the reported cohesion and angle of shearing resistance, sample A is classified as firm clay, sample B as stiff clay, and sample C as soft clay. The superior performance of B is consistent with its higher reported MDD and lower OMC. Recent research on Nigerian clayey soils has also demonstrated that shear strength varies considerably with soil type and treatment (Ojefiaet *al.*, 2024).

Table 6: Summary of Shear Strength Test Results for Three Clay Samples

Sample Label	Cohesion (c) KN/m ²	Angle of Shearing Resistance (φ)
A	42.0	10
B	90.0	20
C	23.0	23

3.7 California bearing ratio (CBR)

The CBR results are presented in Table 7. The 2.5-mm penetration value is normally adopted; however, where the 5.0 mm value is consistently higher after repeating the test, the 5.0 mm value may be adopted in accordance with the applicable CBR procedure. The reported results were therefore repeated and the 5.0-mm values adopted.

Table 7: California Bearing Ratio Test Results for the three Clay Samples at 2.5 mm and 5.0 mm Penetration

Samples Label	CBR at 2.5 mm (%)	CBR at 5.0 mm (%)	Adopted CBR Values
A	4.08	6.44	6.44
B	3.01	5.15	5.15
C	3.72	4.01	4.01

The reported CBR indicates that sample C has the weakest bearing performance, whereas A and B perform comparatively better. A and B is classify as moderate strength soil, since their CBR values is less 5%, the sample A and B can be further classify as clay (ASTM D1883, AASHTO T193, Rehmanet *al.*, 2015, Kassa, 2024). Low CBR generally indicates poor subgrade performance and possible need for improvement. Pule and Yendaw (2024) showed that CBR is strongly influenced by MDD, OMC, LL and PI. Recent Nigerian studies likewise report substantial differences in CBR among clay deposits, demonstrating the importance of location and compaction conditions.

3.8 Consolidation test results

Equations 1 and 2 were used to determine the time required for 99% consolidation, assuming a drainage path, d , equal to unity. The results in Table 8 indicate that the coefficients of compressibility and volume compressibility, compression index and time required for 99% consolidation are highest for C, followed by A and B. Conversely, the coefficient of consolidation is highest for B, followed by A and C.

$$T_v = 1.781 - 0.933 \log(100 - U\%) \quad (1)$$

$$t_{99} = \frac{T_v \times d^2}{C_v} \quad (2)$$

Table 8: Oedometer/Consolidometer Test Result for Clay Samples

Sample Label	Coefficient Consolidation (a_v) m^2/KN	Coefficient of Volume Consolidation (m_v) m^2/KN	Compressibility Index (C_c)	Coefficient of Consolidation (C_v) $m^2/secs$	Time Taken for 99% Consolidation (Days)
A	8.30×10^{-4}	7.21×10^{-4}	6.82×10^{-4}	7.07×10^{-7}	28
B	1.55×10^{-4}	1.15×10^{-4}	3.42×10^{-4}	8.83×10^{-7}	23
C	9.70×10^{-4}	7.39×10^{-4}	7.42×10^{-4}	6.90×10^{-7}	30

The greater compressibility of C indicates comparatively greater susceptibility to settlement, whereas the higher coefficient of consolidation of B suggests faster dissipation of excess pore-water pressure under the stated test conditions. Recent work on residual Nigerian clay has also demonstrated the importance of consolidation, permeability and compaction characteristics in assessing engineering suitability (William *et al.*, 2024).

Overall, the results demonstrate substantial spatial variation in the engineering behaviour of the three clay deposits. This agrees with Adebimpeet *al.* (2026), who found that Ekitikaolinitic clays with broadly similar index properties nevertheless exhibited significant differences in strength and subgrade performance. It also agrees with

Andre-Obayanjuet *al.* (2022), whose Southwestern Nigerian clay deposits showed wide ranges in plasticity, compaction and CBR.

4. CONCLUSION

The results indicate that sample B possesses the most favourable overall geotechnical properties, followed by A and C. Sample B exhibits the highest reported MDD, lowest OMC and comparatively better bearing and strength characteristics. Sample A shows intermediate performance, whereas sample C records comparatively higher compressibility and lower bearing performance.

The three clay samples may be considered for subgrade applications only after appropriate improvement where required and after comparison with the applicable road-material specifications. Stabilization using cement, lime, fly ash or suitable fibre/ash materials may improve their engineering properties. Recent studies have demonstrated that appropriate stabilization can improve the CBR and shear strength of clayey soils (Ojefia *et al.*, 2024; Geotechnical characteristics of fine-grained soil with wood ash, 2024).

Therefore, sample B appears to offer the best geotechnical performance among the three samples. Base on the geotechnical properties of the three clay samples, stabilizing clay B will be financially viable and give the best result.

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