Engineering Geological Evaluation of Some Clay Deposits in Dahomey Basin Southwestern Nigeria.

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***Abstract-** Qualitative evaluations of clay deposits in Erusu-Akoko, Southwestern, Nigeria, were executed with a view to determining its quality and possible utilities. Four representative bulk samples were collected and subjected to geotechnical analysis which included; grain size analysis, bulk density, unconfined compression strength test, modulus of rupture, permeability, compaction and mineralogy of analysis. The result of the geotechnical analysis showed that the liquid limit ranged from 48.30 –52.30 % with a mean value of 50.10 % and its plasticity index limit ranged from 26.0 – 31.9 with a main value of 20.30 % which is an indication of intermediate plasticity. The plastic limit ranged from 26.0 – 31.90 % with a mean value of 29.4 % which implies that the clay can withstand volumetric shrinkage on heating and exhibit a low to medium swelling potential when wet. The amount of fine fractions about 60.41 – 75.32 %, clay sized fractions about 10 – 22 %, average compressive strength 230 kpa, average bulk density 2.03 g/cm^3, average porosity 27.4 %, average compaction 1.92 %, permeability coefficient 1.7 x 10^{-5} cm/s, average firing temperature 1350^{o}C and average modulus rupture 1100^{o}C showed that the clay possesses properties of a good liner for landfill, pottery, refractory materials and firebricks. The study showed that the clay deposits in the study area can be used for the production of ceramic, pottery, firebricks, blast furnace for metals and refractories.*

***Keywords:** Clay deposit, pottery, Geotechnical Assessments, Refractories and Ceramics*

I. INTRODUCTION

Background

Clay is an important mineral resources that has been mined since time immemorial when it has been used for primitive applications such as ceramics, pharmaceutical and building construction industry (24). (13) Critically assessed the industrial potentials of the clay deposits in Erusu-Akoko based on the geotechnical and mineralogical characteristics and suggested that the clay deposits in the area are suitable for the production of refractories, bricks and ceramics. Numerous studies have shown that some clays in Nigeria are good for brick makings based on their natural swelling potentials, cold crushing strength and natural water content(6,17). (2) Suggested that clay deposits can occur majorly as two types in Nigeria namely; the residual clay in the basement complex and the transported clay deposits dominantly in the sedimentary basins, and clays have been found in areas such as Ode-Aye, Omi-Adio, Jos and Imope.

(1,25,2) have discovered clay in some parts of Nigeria useful for furnace construction as a result of their high thermal shock resisitance,refractories values, bulk density and cold crushing strength. However, to positively address the major economic and social problems such as social unrest, unemployment and over- dependency on foreign products rampant in Nigeria today, it becomes imperative and of paramount importance to diversify the major source of revenue from crude oil and gas (30) and used the available mineral resources such as clay sand effectively to boost the nation economy as a result of their contribution to the nation's wealth base and socio-economic development.

However, the focus of this work is to investigate the occurrence ot the clay deposits in Erusu-Akoko(figure 1) and its environs as well as to evaluate its possible applications.

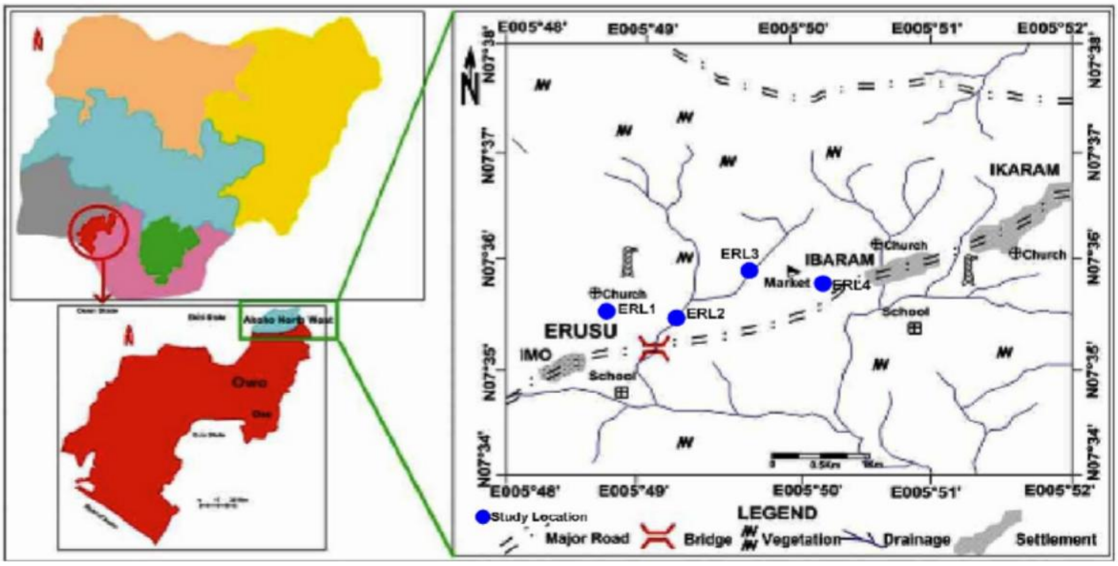

Figure 1: Location map of the study area (Insight is map of Nigeria and Ondo State). THE STUDY AREA

The study area is located in the North part of AkokoWest local government area (L.G.A.) of Ondo state, Southwestern, Nigeria, (Figure 1) and lies between Latitude 7^0 30'N and 7^0 35'N and Longitude 5^0 45'E and 5^0 50'E occurring in the northern part of Owo, Northwestern sheet (225) of the Federal Survey of Nigeria (1978).The area measures about 60 square kilometer The study area is accessible with Erusu-Akoko being dissected by a tarred road linking the area with main Imo-Arigidi -Erusu-Akoko road to the west (Figure 1.1).The road has been upgraded and serves as a link to Ibaramu from Arigidi. The bifurcated road serves as a major transit road for heavy duty vehicles travelling to and from the northern part of the country.

The vegetation of the study area is typical of tropical rainforest. The area is covered by thick evergreen forest with the exception of some places where settlement and farming have resulted in the removal of the original forest cover and has dense savannah. Different variations of vegetation occur in the area and the plant grown in the area include both annual crops such as cassava, maize and perennial crops such as kola nut, cocoa, palm tree etc. The climate of the study area is hot, humid, and tropical. The wet season covers the period of April to October while the dry season covers period of November to March. The study area is of moderate relief with a few high lands at the southwestern part of the study area. There is presence of a prominent ridge in the south-eastern part of the study area and northwestern area and low land in the southern part. The area is moderately to highly undulating with an average elevation of about 362m.

GEOLOGY OF THE STUDY AREA

Erusu- Akoko area comprises mainly of gneisses in association with porphyritic older granites, charnokite, pegmatite, aplite, granites, vein quartz and amphibolitic intrusions (figure 2.2). The gneisses in the area occur as grey gneiss and quartzo-feldspathic gneiss respectively, granodiorite to tonaltic quartz-dioritic in composition. The grey gneiss occurs within the granite gneiss. It is dark grey to dark green in colour and medium coarse grained with well- developed thin mineralogical bands. The light-colored bands are quartzo-feldspathic while the dark coloured bands care rich in ferro- magnessian mineral. The grey gneiss contains intrusions of pegmatite and quartzo-feldspathic veins and is regarded as the oldest rock in the area.

There are five major types of rocks encountered in the mapped area (figure 2).These rocks are granite, granite gneiss,augen gneiss, charnockite and grey gneiss.

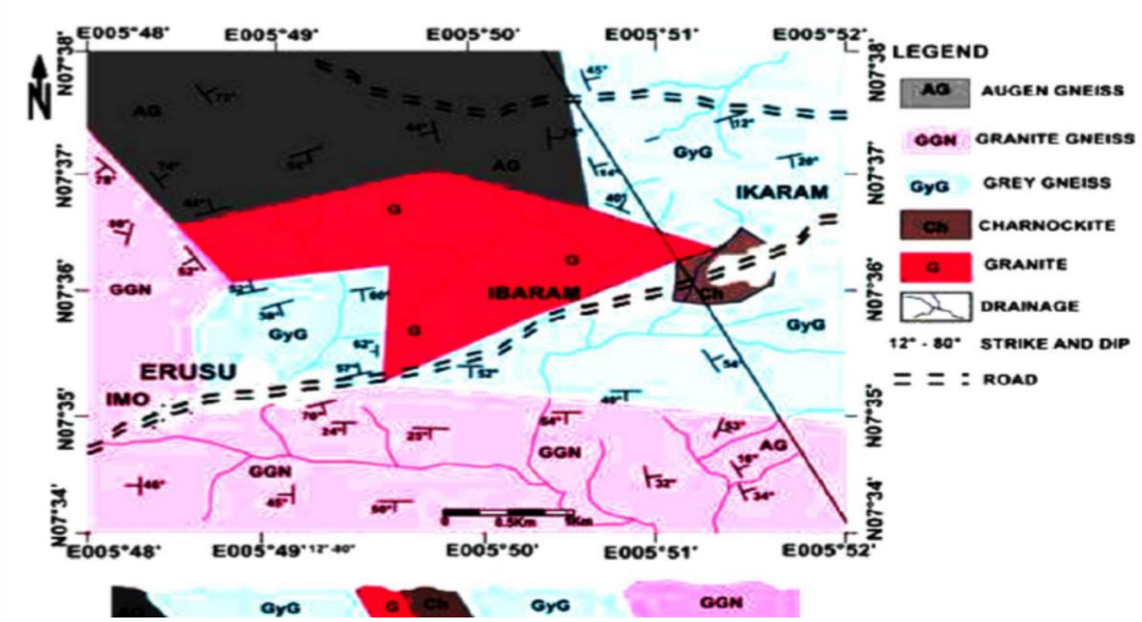

Figure 2: showing geological map of the study area (this study)

II. MATERIALS AND METHODS

Field Description of Samples

The field work was carried out between the Month of August and September; 2020.it involved mainly the collection of samples from different outcrops in various part of Erusu-Akoko, Ondo state, Nigeria. Ten different representative samples were collected using hammer and these specimens are kept in the rock bag and taking to the laboratory for petrographic analysis.

Geotechnical Analysis

For a detailed qualitative assessment of the clay samples in the study area, four representative samples were collected with GPS referencing in order to ascertain their exact points of collections. The four samples were collected at the depth of 2-3m using a digger, cutlass and spade
The collected samples were packed in polythene bags and each bag labeled for easy recognition. The collected samples were taken to the laboratory for different geotechnical analysis. The four soil samples were subjected to physical properties test, moulding and firing parameters in order to determine their suitability for different industrial utilities. The samples were prepared for testing by crushing using a jaw crusher, followed by gently grinding the samples to avoid destruction of the structure of the minerals. Samples were air-dried for two weeks immediately after removing samples for the determination of moisture contents to facilitate the sieving process in the laboratory for geotechnical investigation and clay mineralogical analysis.

The qualitative characterization of the clay deposits in Erusu-Akoko, was carried by subjecting the collected samples to geotechnical analysis in two standard laboratories in Nigeria. The Atterberg limit test, Natural moisture content test, Plasticity index test, clay content, Ph and bleaching test, sieve analysis test, permeability test and compression test were the different geotechnical tests conducted on the four samples and this was carried out at Civil Engineering soil laboratory, Federal University of technology, Minna, Niger state, Nigeria. While the linear shrinkage test ,apparent porosity test, specific gravity test, modulus of rupture test, California bearing ratio test, unconfined compressive strength test, firing test and compaction test were conducted in Federal Institute of Engineering Laboratory, Oshodi in Lagos State, Nigeria. The laboratory analyses were carried out in accordance to British standard methods of test for soils for Civil Engineering purposes. (B.S 1377: part2:1990).

The collected soil samples were subjected to the following geotechnical tests;

1. Apparent porosity
2. Modulus of rupture
3. Natural moisture content
4. Atterberg limit test (liquid, limit, plastic limits, shrinkage limit, and plastic index).
5. Specific gravity.

6. Percentage of clay contents
7. PH and bleaching test
8. Particle size distribution test
9. Compaction
10. California bearing ratio (CBR)
11. Firing test
12. Permeability
13. Unconfined compressive strength
14. Thermal shock resistance (TSR)
15. Hydraulic conductivity

III. PRESENTATION, INTERPRETATION, AND DISCUSSION OF RESULTS

Presentation of Results

The results of the three analysis performed on different samples collected from Erusu-Akoko area, are presented below;

Natural Moisture Content

Table 1 and Figure 4.1 presented the results of the Natural moisture contents of Erusu-Akoko clay deposits. The moisture content for ERL1, ERL2, ERL3 and ERL4 is 13.10 % for ERL1,
13.50 % for ERL2, 22.90 % for ERL3 and 29.50 % for ERL4. The natural moisture content is important in understanding the engineering proportions of soil for construction and industrial use.

The moisture content is a functions of ratio and specific gravities of the clay samples. The high moisture content obtained confirms to the generally accepted high porosity and low permeability properties of clay (25). The modified classification of plasticity chart and plotted for the clay sample presented in figure 3 and figure 4showed that the soil samples fall above the "A" line within the region of CL [which is inorganic clays of intermediate plasticity, (32) stated that soils with liquid limit value less than 35% are grouped as low plasticity while those with values between35 and 50 are classified as intermediate plasticity] as such the moisture content value of the study clay deposits confirm to the accepted standard by (32) since the range of the moisture contents in the study area falls between 13.10 % - 29.50 % and the average moisture natural contents of the sample is 17.20 % which confirm to the accepted high porosity and low mouldability character is of a clayey materials with a range value of > 30 % for soil good for engineering purposes such as landfills, brick making and construction as stipulated by (25).

Table 1: Some Engineering properties of the clays, (value of natural moisture contents MC), liquid limit (LL), Plastic Limit (PL), Plasticity Index (P1), linear shrinkage (LS) and specific gravity (S.G) of the clay sample.

LOCATION	Average % of Particles				Atterberg Limits			Average %		%	PH	% Lost on Ignition	(%) Linear	SG
	Gravel	Clay	Silt	Sand	Liquid	Plastic	Plastic							
		(>2mm)	10.063-2mm)	10.002-0.063mm)	>0.02 mm	Liquid Limit (%)	Plasticity (%)	Plasticity Index (%)	Moisture	Clay Control				
ERL 1	A	3.3	69.5	16.2	17.1	52.2	21.5	30.7	13.1	73.21	5.24	11.8	8.9	2.71
ERL 2	B	4.4	70.00	12.0	15.2	50.4	18.3	31.9	13.5	70.32	5.32	15.3	8.5	2.39
ERL 3	C	4.9	70.0	18.1	8.0	48.4	22.1	26.3	22.9	69.41	5.61	15.0	8.7	2.70
ERL4	D	4.2	68.7	19.1	10.0	48.3	22.3	26.0	29.5	75.32	4.96	12.05	8.9	2.75

Atterberg Limit

Table 1 contains the summary of the values of the consistency limits while Figure 3 shows the Casagrande chart classification of the soil. The plasticity index varies from 26.0 to 31.90 %.The results of the liquid limits is presented in Table 1 as ERL1 has 52.20 %, ERL2 has 50.40 %, ERL3 has 48.40 % and ERL4 has 48.30 %. According to engineering specifications, the liquid limit value less than 30% shows low plasticity between 35 % and 50 % (27).

The range of values of the plastic limits is shown in Table1 as (18.3-22.30 %).This fall within the range of value of intermediate plasticity and compressibility as such plotting in the inorganic clay group of the Casagrande chart. With the plasticity range of (18.30-22.30 %), it is confirmed that the four clay samples from the study area are suitable for ceramic production as presented by (15) who proposed a range between 10 and 60 % for clay used for ceramic production. The plasticity chart in figure 4 and 3 shows that the soils belong to the inorganic clay of intermediate plasticity. Three types of clay minerals were confirmed from the plotted modified plasticity chart (montmorrilonite, illite and kaolinite). The plots on the charts showed that Kaolin is the predominant clay mineral with 40 % followed by the other two minerals (illite and montmorrilonite) with each having 30 % figure 4 (8).

The range of the plasticity index for the four soil samples is between 26.0% and 31.90% with ERL2 having the highest plasticity index of 31.90% while the ERL4 has the least plasticity index of 26.0%. liquid limit of less than 90 % was recommended for landfill barrier soils by (28).

The plot of the plasticity index against the liquid limit on the Casagrande chart (10) shows that the four samples (ERL1, ERL2, ERL3 and ERL4) plotted within the inorganic clays of medium or intermediate plasticity.

With reference to the soil classification by (8) Erusu-Akoko clay deposits is considered as a kaolinitic clay deposit. These clays are good materials for landfill liners as they all meet the engineering requirements of (P.I.>7%) condition.

The results of the liquid limit were more than 20 % but less than 90 %. The result findings of the study clay deposits conform to that of (9,21) and therefore, the soil in the study area can be recommended as landfill barrier soils.

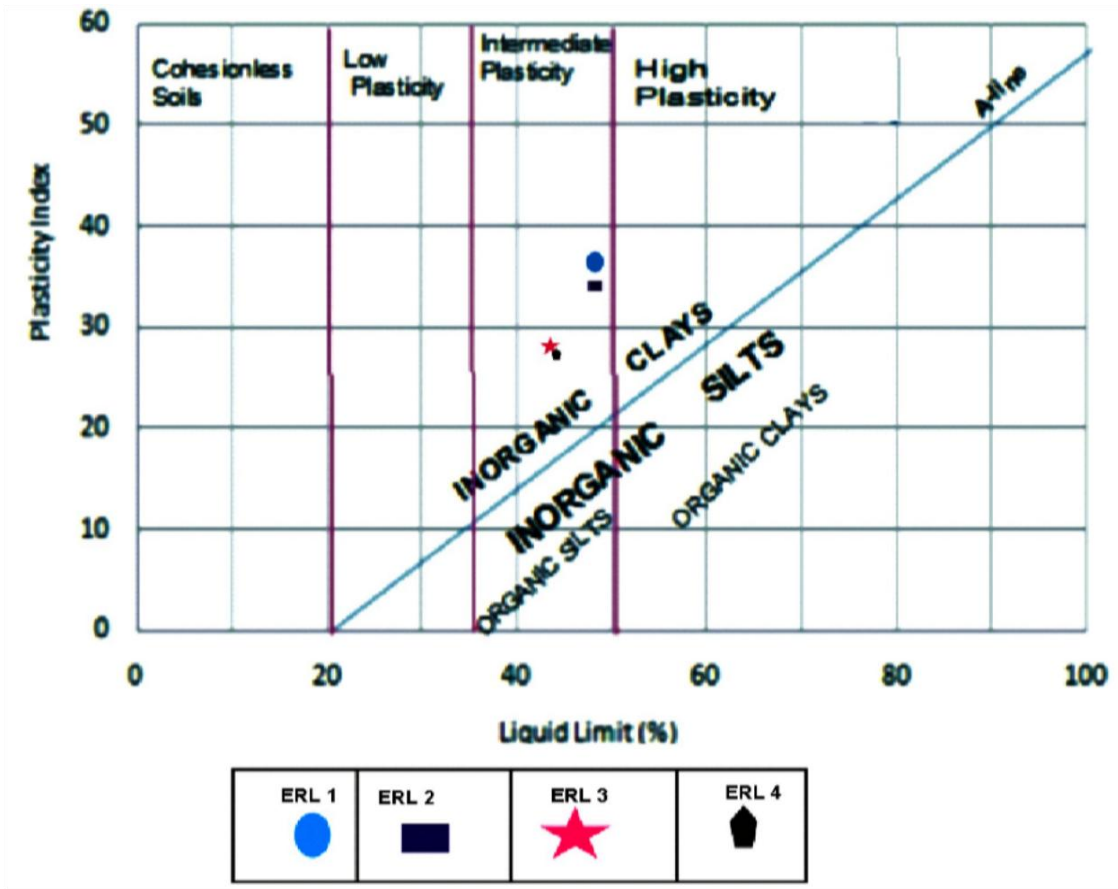

Figure 3: Plasticity curve after (12)

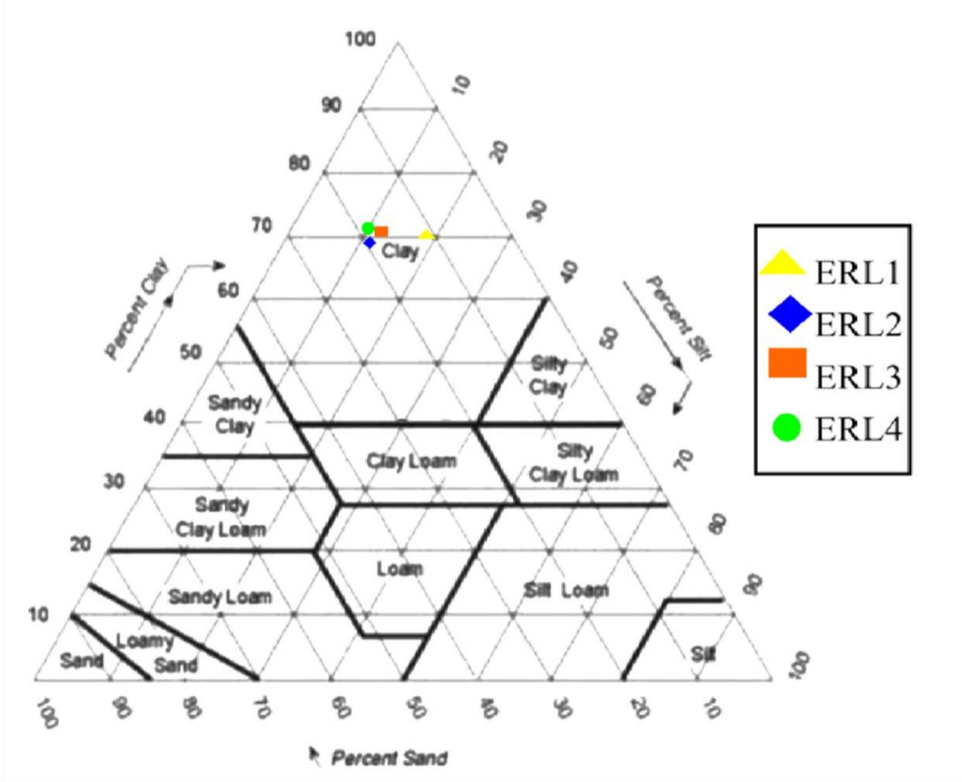

Figure 4: Textural classification of clay samples (After 8).

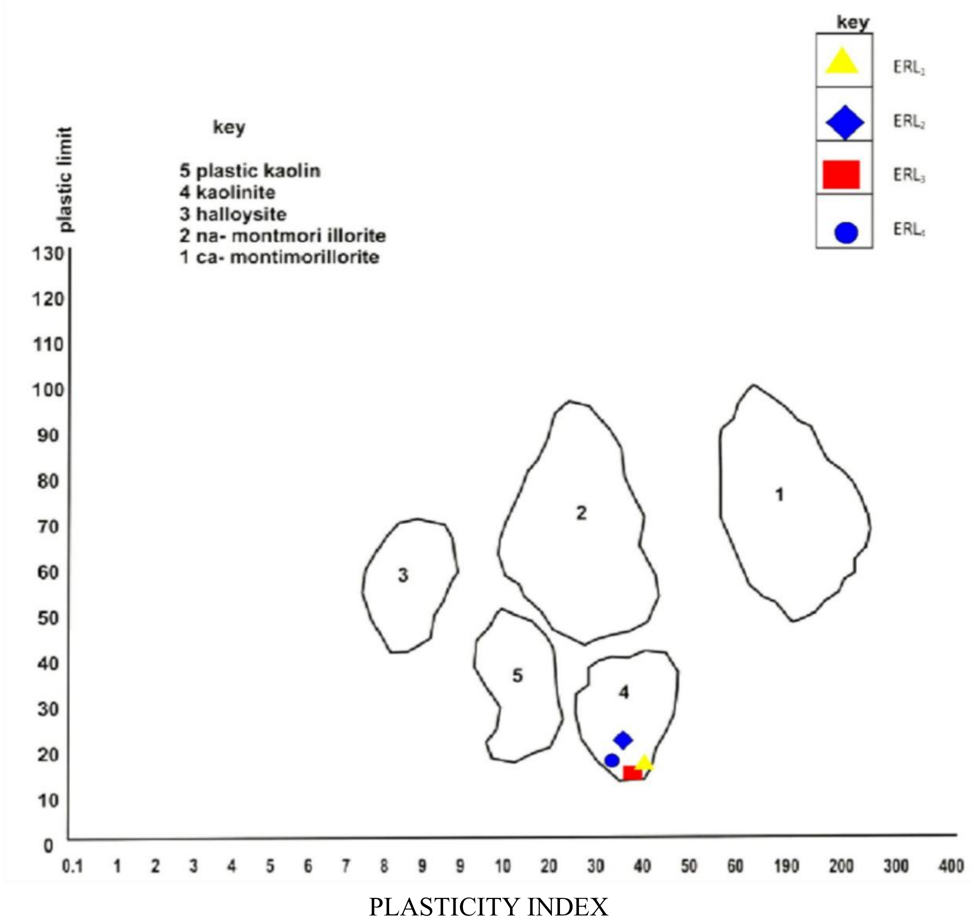

Figure 5: Showing classification identification of chart using plastic limit and plastic index as parameter (After 8).

Linear Shrinkage and Apparent Porosity

Figure 6 and Table 3 present the linear shrinkage and apparent porosity results of the clay bricks from ERL1, ERL2, ERL3 and ERL4 respectively. It is observed that there is a slightly decreased in the linear shrinkages as the firing temperature increased from 900°c to 1200°C.This decrease agrees with a decrease in apparent porosities of the samples. As the firing temperature increases, the moisture (figure 5 and table 2) within the bricks changes into vapour and diffuse out of the brick, thereby creating vacant sites within the clay. Clay particles then migrate to occupy the vacant sites. This results in the shrinkage of the clay molecules and collapse of the voids within the brick. At the point of intersection of clay grains, necking occur leading to the fusion of the clay grains. This is termed grain consolidation which leads to the formation of the bonds which increased density (Figure 7) of the bricks due to reduced porosities within the volume of the bricks. It was also found that the linear shrinkage was proportional to the plastic index and clay content of the soils and inversely proportional to the shrinkage limit value (25). It is also worth noting that soil shrinkage will result in cracks in the soil. The cracks make the soil more permeable to water and may damage geotechnical structures (31) as such soil with shrinkage value greater than 10 % should not be used for engineering constructions. Such as brick making, dam construction and pottery (31). Since all the shrinkage limits of the study clay deposits are below 10^0C, the study clay deposits are good for engineering construction such as landfill liners, brick making and pottery.

Table 2: Variation of fire linear shrinkage in (%) with temperature

S/N	900ºC	1000ºC	1100ºC	1200ºC
ERL1	5.0	7.0	8.0	8.5
ERL2	7.0	8.0	8.5	9.5
ERL3	4.0	6.0	7.0	7.5
ERL4	6.0	7.0	7.5	8.0

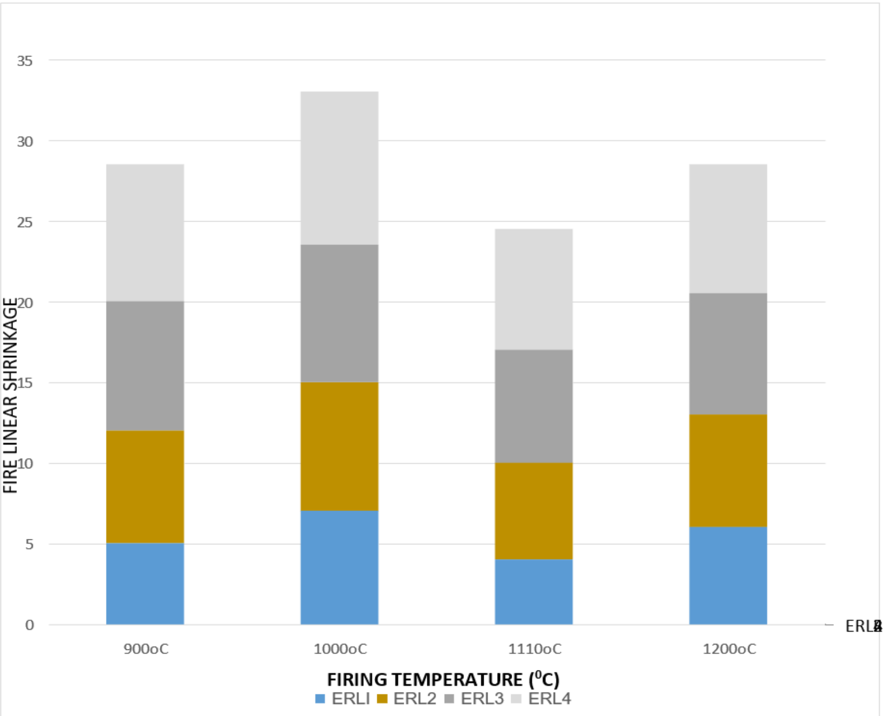

Figure 6: Showing percentage of fire linear shrinkage with temperature

Specific Gravity of grains

Table 1 shows the specific gravity of the four samples (ERL1, ERL2, ERL3 and ERL 4) collected from the study area. The specific gravity enables appropriate design of the equipment which are beneficiary to the removal of the non-clay fractions. The specific gravity of the four samples fall within the range of 2.39-2.75. Sample ERL1 has 2.71, ER l2

has 2.39 with the minimum value, ERL 3 has 2.70 and ER l4 has the maximum value with 2.75.
(28) stipulated that the increase in specific gravity lead to an increase in the shear strength of the sub-grade materials which is used in constructional work such as road construction. Since the specific gravity of the four soil samples fall within the standardized engineering range of 2.73 was specified by (29), hence, the four clay samples collected from the study area can be used for constructional works such as road construction and liners in Sanitary landfill (25).

Water Absorption capacity

The water absorption capacity reduces as the particles shrink together and hence, porosity decreases. Figure 7 and Table 4, shows that the water absorption decreases with apparent porosity. The average percentage of the water absorption capacity of the fired disc (figure 4.5) at 900°C, 1000°c, 1100°C and 1200°C range from 13.39-16.0 %, 9.95-14.67 %, 7.75-12.38 % and
5.36-10.42 % respectively. This reveals that consistency decrease with increase in temperature. Since the water absorption properties of the collected clay samples directly depend on the specific gravity of the soil therefore, the four clay samples are good for brick making and ceramic works (6).

Table3: Showing percentage of water absorption of the clay with temperature

S/N	900°C	1000°C	1100°C	1200°C
ERL1	16.0	14.67	12.38	10.42
ERL2	14.64	13.36	12.21	7.85
ERL3	13.89	11.29	11.40	6.45
ERL4	11.29	9.95	7.75	5.36

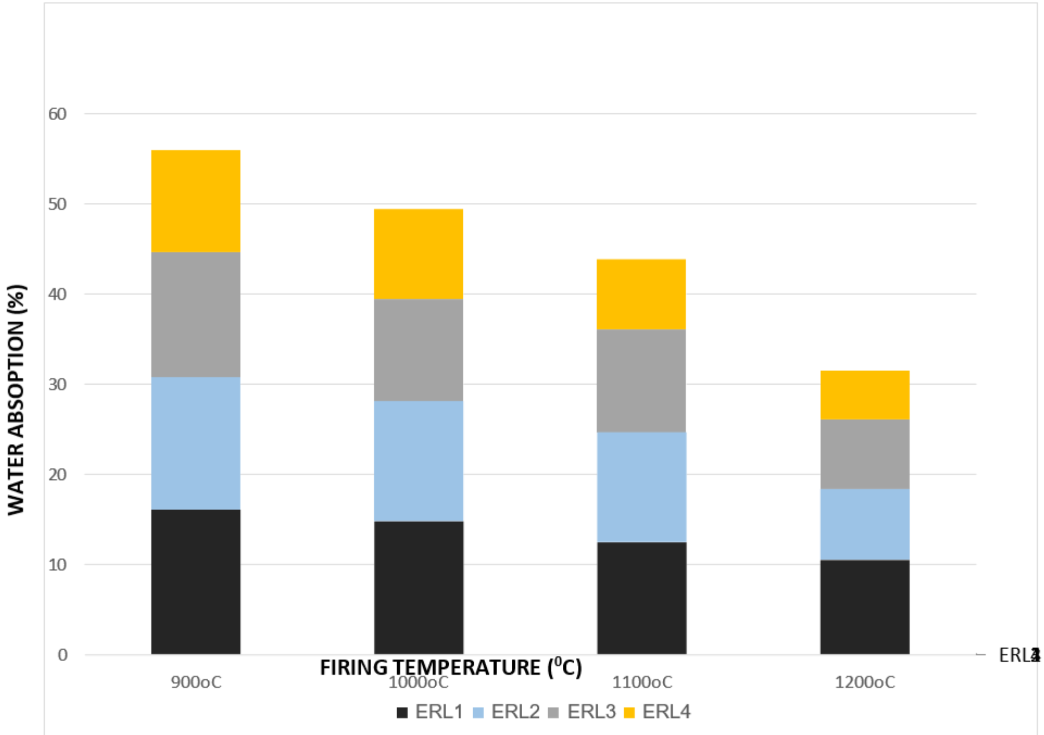

Figure 7: Water absorption capacity of clay samples with temperature

Modulus of Rupture (PSI)
Figure 8 and Table 5, shows the modulus of rupture obtained from the samples collected from the study area. The modulus of rupture of the clay sample at 900°C, 1000°C, 1100°C and 1200°C ranges from (219.6-364 PSI for ERL1), (352.94-430.10 PSI for ERL2),(480.71-580.64
PSI for ERL3) and (732.30-840.06 PSI for ERL4) respectively. It can be seen in Figure 4.7 that the modulus of rupture of the four clay samples collected from the study area increased with increased in temperature. The liquid increased in amount and

upon cooling, solidifies to form glass at a temperature above 1000oc and thereby acting as a cementing materials holding the masses together. (12) propounded a range of 200-700 PSI for a clayey material to be used as refractories and for blast furnaces. Since the values obtained conformed to this specification, hence, the four soil from Erusu-Akoko can be used as raw materials for blast furnace and as refractories (17).

Table 4: Showing percentage of modulus of rupture (PSI)

S/N	900°C	1000°C	1100°C	1200°C
ERL1	364.00	423.54	480.91	800.62
ERL2	340.20	430.10	500.40	840.06
ERL3	219.60	391.30	482.29	732.30
ERL4	325.62	352.94	580.64	800.21

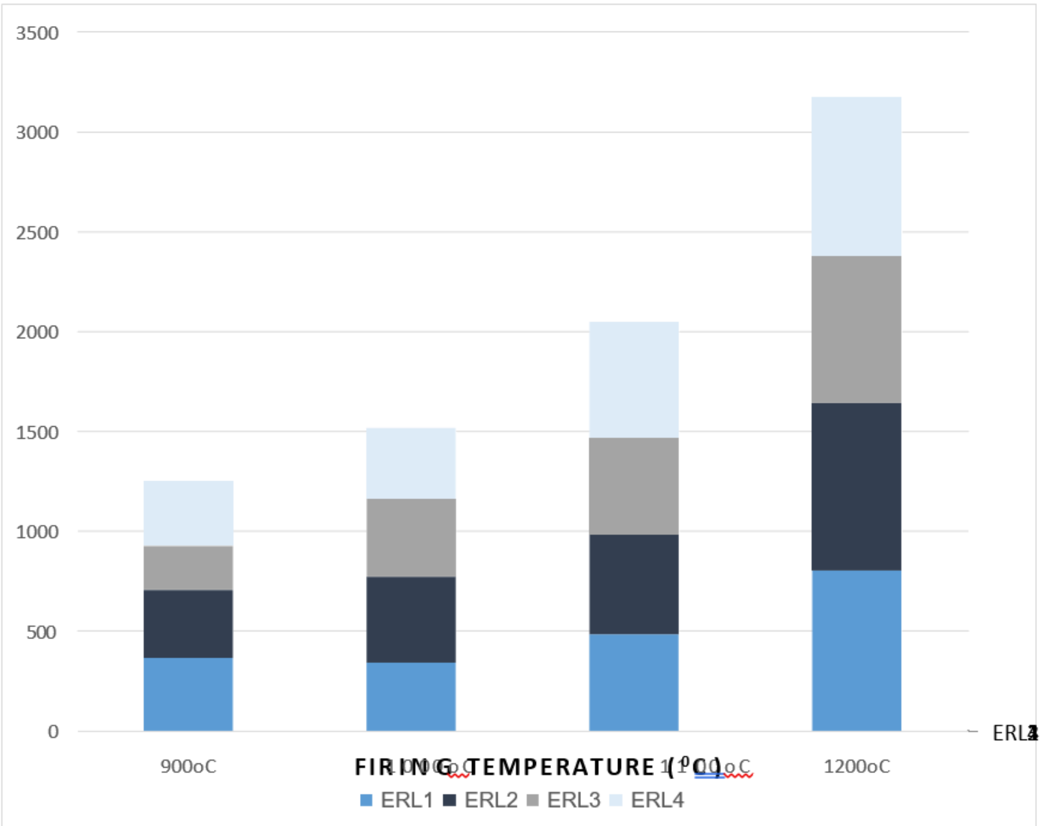

Figure8: Showing modulus of rupture with firing temperature

4.1.7 Clay Content

The clay contents observed in the sample collected from the study area that has the least amount of clay particles portrayed the highest percentage of clay particles table 1. This clay content value fall between 69.41 and 75.32 %. Interestingly, the Erusu-Akoko (ERL_4) sample that has the least amount of clay size particles has the highest percentage of clay (Table 1). However the percentage is less than 88.25 % which is the amounts of fines % of clay and silt size particles. Implicitly, this revealed that some of the clay size particles are silts. The appreciable clay content in the samples rather than silts favours easy mouldability and high plasticity (6).

4.1.8 Porosity and Bulk Density

Figure 9 and Table 6, displayed the porosities and bulk densities of the fired bricks produced from clay obtained from Erusu-Akoko (ERL1, ERL2, ERL3 and ERL4). It is observed that the Porosities vary with the bulk densities. Clay bricks from site ERL1 has percentage Porosities ranging from 32.02 to 40.36 %, ERL2 has 18.32 to 30.34 %,ERL3 has 28.94 to 40.46 % and that from ERL4 has a Porosities range from 27.30 to 32.64 %.Their respective average bulk densities vary from 1.38

g/cm^3 to 2.93 g/cm^3.The porosity value of the brick samples from ERL1, ERL2, ERL3 and ERL4 are in line with recommended standard range (10 to 40.50 %) for fired clay refractory by (20). In addition, the bulk densities fall approximately within the range of 1.2-2.4 g/cm^3 for dense fire bricks (7)

Table 5: Showing percentage of bulk density (kg/m^3) of the clay with increasing firing temperature

S/N	900°C	1000°C	1100°C	1200°C
ERL1	1.38	1.50	2.67	2.75
ERL2	1.42	1.60	2.53	2.67
ERL3	1.40	1.80	2.00	2.84
ERL4	1.60	1.72	1.90	2.93

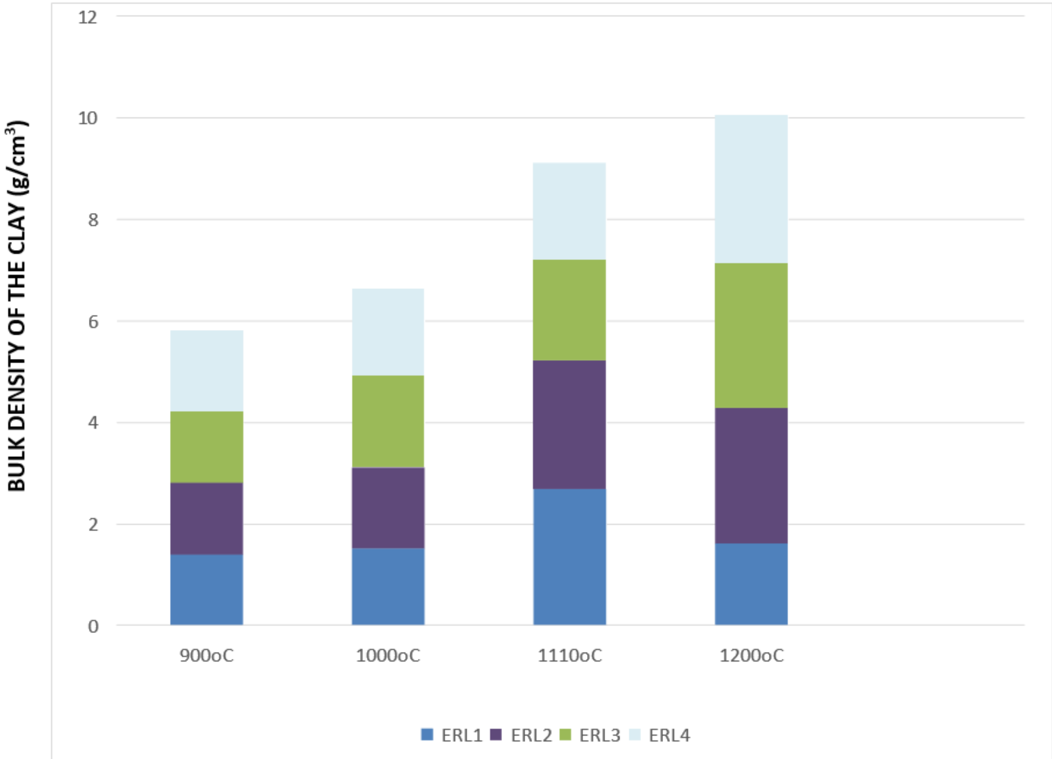

Figure 9: bulk density of the clay with increasing firing temperature.

Particle Size Distribution

The grading curves for the soil samples in the study area are presented in Figure 10 while Table 7 shows the different particle sizes obtained from the four samples (ERL1, ERL2, ERL3 and ERL4). The generally high amounts of fine fractions (about 69.50 %-70.0 %) are typical of fine grained soil. The value of the clay particle observed in each of the samples is given as ERL1 (69.5%) of the clay materials, ERL2 (70.0 %), ERL3 (70.0 %) and ERL4 (68.70 %) while the percentage of sand in the samples is given as ERL1 (16.20 %), ERL2 (12.00%), ERL3 (18.10%) and ERL4 (19.10 %). The percentage of silt in the samples is given as (ERL1 (3.3 %), ERL2 (4.4%), ERL3 (4.7 %) and ERL4 (4.2 %).The gravel percentage of the clay samples are relatively low with ERL1 having (2.2 %), ERL2 has (1.18 %), ERL3 has (2.15 %) and ERL4 has(1.43%). (27) stipulated amount of fines of at least 30% for good liners for landfills. The amount of silty size fraction (about 12 % to 18 %) are not too different from the minimum stipulated value of 15%.These values are relatively high and good for their mouldability and plasticity (25). It is established that the four clay samples collected from the study area are well-graded and poorly sorted. According to the Unified Classification System (USCS), only soil samples plotted within percentage of silt and clay at (60% and 5%) are usually described as well-graded clayey sand or gravel. According to engineering specification , any soil with 15.35% sand, will display high clay content, low silt and low sand content, will possess low permeability which is an important property required for the construction of sanitary landfill liner

(27).

Table 6 showing the percentage of grain size analysis

Sample	Percentage passing (%)										
	Sieve size (mm)										
	5.00	3.250	2.360	2.00	1.80	0.85	0.600	0.45	0.300	0.150	0.075
ERL 1	99.13	97.68	96.00	95.30	90.21	86.19	80.62	80.47	7.70	60.77	50,79
ERL 2	99.83	99.50	97.62	97.09	94.00	91.34	86.39	70.03	61.92	50.39	40.62
ERL3	97.30	98.0	96.10	95.70	92.00	87.29	83.61	60.27	56.89	48.07	39.63
ERL 4	96.96	97.52	97.50	94.10	90.21	94.09	91.20	82.60	81.57	70.00	55.01

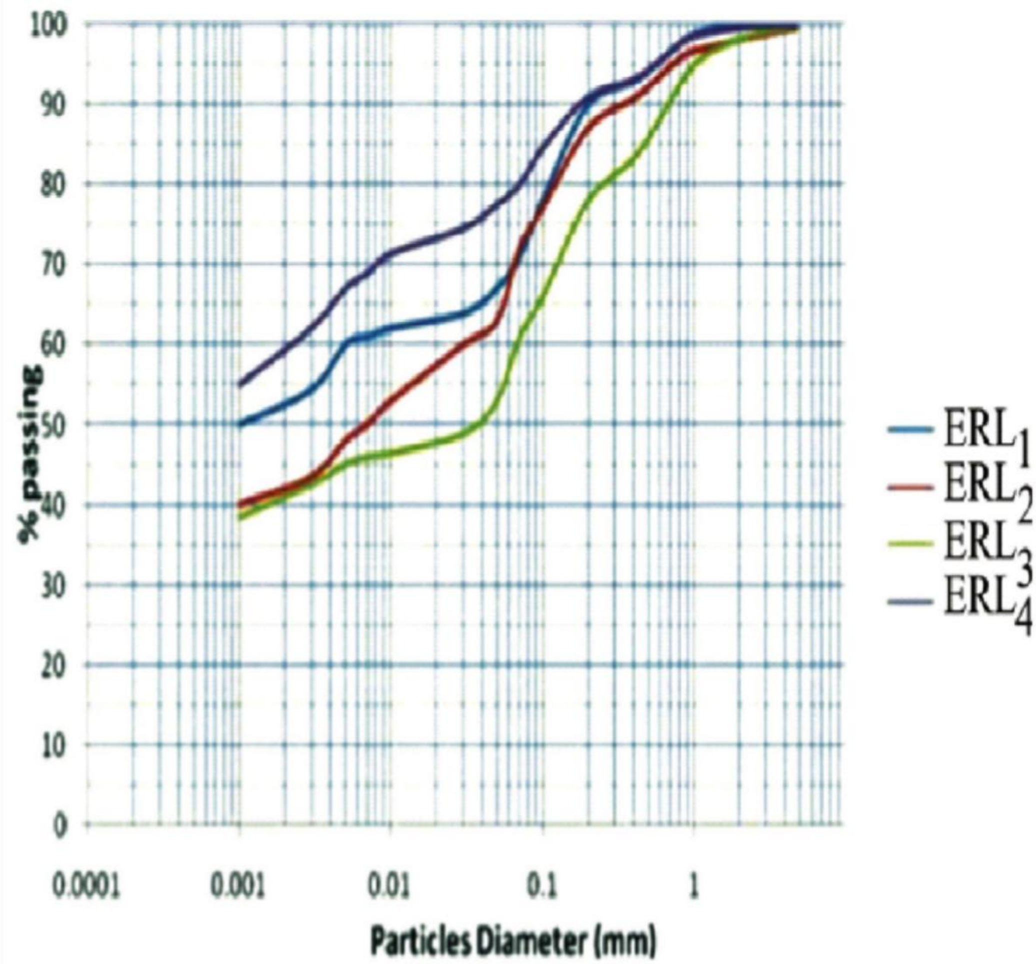

Figure 10: Showing the grading curve of the samples

4.1.10 California Bearing Ratio

Table 7 shows California bearing ratio for the soaked values in Erusu-Akoko as ERL1 having 24%, ERL2 having 13.0%, ERL3 having 33.0% and ERL4 having 20.0% respectively. In the same vein, the values for the California Bearing ratio for the unsoaked values are as follows; ERL1 has 50%, ERL2 has 48%, ERL3 has 47% and ERL4 has 35% respectively. The analyzed samples from the study area have the required 40 % unsoaked and 15% soaked CBR values recommended for highway sub-based and sub-grade soils by Federal Ministry of Works and Housing, specification for roads and bridges. The study clay deposits showed decrees in CBR value after soaking. The soaked CBR meets minimum required CBR standard of 15 % for sub-base courses and the road sub-base, there is a reduction in strength as a result soaking of the compacted clay samples (18). Based on this, the study sub can be classified as having good CBR and can be used a sub-grade and sub-fill materials as well as foundation liner materials as stated by (25).

Unconfined Compressive Strength

Figure 4.10 and table 8 show the result of unconfined compressive strength test (UCS). The shear strength was determined by the peak pressure from the unconfined compressive strength (UCS) test after all the samples were cured. The cold crushing strength of the collected clay samples from the four locations in the study area ERL1 (432 kg/cm^3), ERL2 (493 kg/cm^3, ERL3 (500 kg/cm^3 and ERL4 452 kg/cm^3 respectively. However, the UCS of the bricks obtained at 1200^{0}C for ERL1, ERL2, ERL3 and ERL4 are 360 kpa, 130 kpa, 120kpa and 110 kpa for the incured UCS while 420 kpa, 373kpa, 400 kpa and 410 kpa for the cure UCS respectively. The high UCS recorded for the four clay bricks could be due to the high percentage of fine fractions filling void spaces and the interlocking of the coarse clay materials hence, reducing the compressibility, porosity and deformation and thus increasing the shear strength of the clay deposits. The UCS of the study clay samples conformed to the stipulated range of 100 kpa for strength at peak and soil used as liners for landfill (20). Since the cold crushing strength is a useful indicator of any soil to be used as a refractories and the cold crushing strength of the study clay samples conformed to the stipulated range of 100 kpa proposed by (25) for any soil to be used as a refractory as such the clay deposit can be used as refractory and constructional works such as dam embankment, and liners and landfills and brick making as they pour within the range of 100 kpa to 110 kpa which is the minimum standard of soil used for constructional purposes (18).

Table 8: Showing unconfined compressive strength of the clay.

	UNCOFINED COMPRESSIVE STRENGTH	
SAMPLE NO	UNCURED (Kpa)	CURED (kpa)
ERL1	360	420
ERL2	130	373
ERL3	120	400
ERL4	110	410

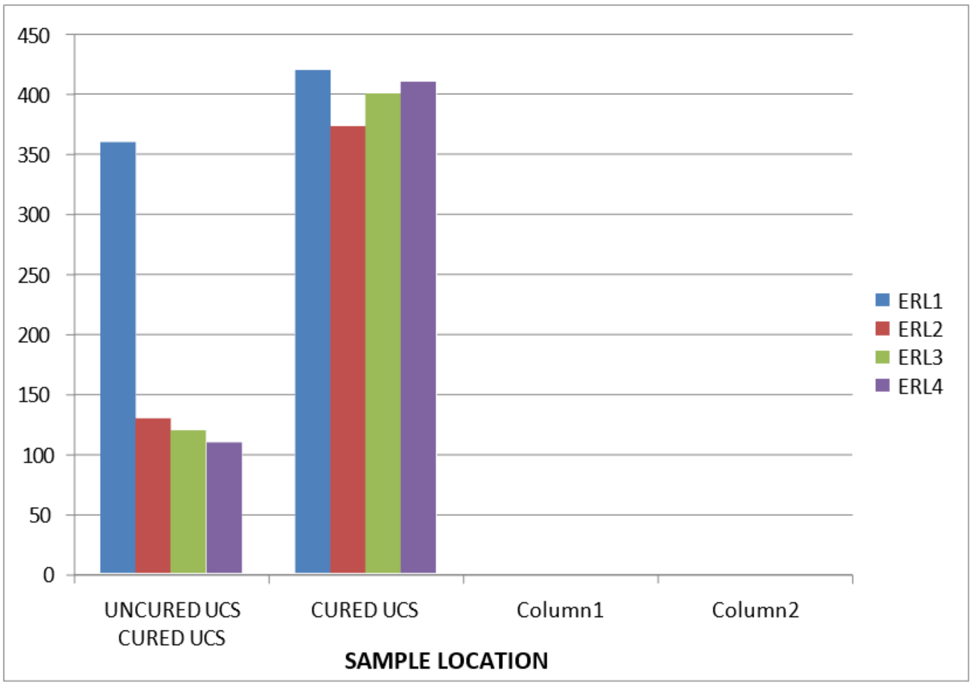

Figure 11: Showing cured and uncured compressive strength

Firing Test and Thermal Shock Resistance (TSR)

Figure 4.11 shows that the firing temperatures of the four bricks collected from the study area (ERL1, ERL2, ERL3 and ERL4). The temperature range is between 1250^{0}c and 1500^{0}c. This temperature is an indication of moderate refractoriness because the normal range for a fire clay brick is 1580 %-1750 % as recommended by engineering specification (6).These high values of refractoriness could be as a result of presence of silica content of a very high percentage. Therefore, the four clay samples will be suitable to be used to processing materials since the melting points do not exceed 1500^0c. The presence of ferric oxide may either discolour or enhance the beauty of the fired product depending on whether a yellow or red material is desired. The presence of ferric oxide (Fe_20_3) imparted a reddish- brown colour on the discs at a temperature of 950-1450 ^{0}C as shown in Figure 11. The presence of Ferric oxide in the four clay samples collected from the study area further justify the existence of high reddishcolouration being observed in the Four samples after firing. in view of this, the four soil samples are suitable for dwindling of contaminants in engineering landfills, as indicated in Table6, sample ERL1, ERL2, ERL3 and ERL4 can be classified as Clayey soil. The four samples are within the stipulated standard range of previous work (1).As such Sample ERL1, ERL2, ERL3 and ERL4 can be used as landfill liners.

Showing Colour change of clay samples before (erl1, erl2, erl3, erl4) after firing, (ERL1, ERL2, ERL3, ERL4)

The results of the thermal shock test (table 9) conducted in the four clay samples collected from the study area indicated that the samples could withdtand study changes in the temperature since the sample survived plus 29 cycles without anu cracks by standard, fire clays are expected to survived 20-30 cycles (27,25,12). However, (19) classified TSR excellent (>30 cycles), good (25-30 cycles), fair (12 to 20 cycles, acceptable (10 – 15 cycles) and very poor (< 10 cycles) by this classification the clay samples thermal resistance shock values were therefore within the "good class" range as such the clay deposit are suitable for the production of fire breaks for thermal application.

Table 9: Thermal Resistance Shock (TRS)

N/S	LOCATION	TSR (CYCLE)
1	ERL1	35
2	ERL2	40
3	ERL3	38
4	ERL4	42

Figure 12: Colour change of clay samples before (erl1, erl2, erl3, erl4) after firing, (ERL1, ERL2, ERL3, ERL4)

Permeability and Hydraulic Conductivity

The amount, distribution and movement of water have an important role in the proportion and behavior of soil. Data from field permeability test are needed in the design of various engineering works, such as cut off wall design of earth dams, to ascertain pumping capacity. The range of value of the study clay deposits permeability are ERL1 0.000017 cm/s, ERL2 0.000015 cm/s, ERL3 0.00017cm/s and ERL4 0.0000015 cm/s (table 11) (5), stipulated a range of 0.00000160 0.00000001 for geology materials soil to be used as barrier soil in landfill soil can used as a barrier soils equal or less than 1x 10^{-7} cm/s meets the criteria for landfills liners (2), as such the study clay deposits are good for landfill liners since the permeability of the collected samples are greater than 1 x10^7 cm/s.

Table 9 shows the hydraulic conductivity of the four clay samples collected from the study area. The hydraulic conductivities of the four clays are ERL1, ERL2, ERL3 and ERL4 (Respectively) (table 10).
The low hydraulic conductivity value of the study clay deposits could be attributed to its high clay and silt size contents, between the course particles, thus, causing a reduction in the sizes controlling the follow and also, causing a reduction in the hydraulic conductivities of the four clay samples. Since the hydraulic conductivity of the four clay samples confirm to the required standard of x10^7 cm/s less stipulated for clay base liner materials (14) as such the four samples can serve as a liner in landfill.

Table 10: Hydraulic conductivity of the soils

Sample No	Effective size (D10) (cm)	Effective Size (D30) (cm)	Effective size (D60) (cm)	K (cm/sec)	Soil type
ERL 1	0.0007	0.03	0.19	1.7x10^{-5}	Clay
ERL 2	0.0008	0.01	0.290	1.5x10^{-5}	Clay
ERL 3	0.0009	0.05	0.212	1.7x10^{-5}	Clay
ERL4	0.0009	0.06	0.213	1.7x10^{-5}	Clay

Table 11: Permeability standard in relation to soil types

SOIL TYPE	K (CM/SEC)	(FT/MM)
Clean gravel	1.0 – 100	2.0 – 200
Coarse sand	1.0 – 0.01	2.0 – 002
Fine sand	0.01- 0.001	0.01 – 0.002
Silty	0.001 – 0000	0.002 – 0.00002
Clay	Less than 0.000001	Less than 0.000002

Compaction

According to AASHTO classification of the soils, all the soil samples have excellent to good ratings of A-1-a to A-2-7 compassion type. The values of Maximum Dry Density (MDD) for samples ERL_1, ERL_2, ERL_3 and ERL_4 are 1.99 kg/m^3, 1.89 kg/m^3, 1.94 kg/m^3 and 1.97 kg/m^3 respectively as shown in Table 11. The corresponding Optimum Moisture Content (OMC) of samples ERL_1, ERL_2, ERL_3 and ERL_4 are11.8 %, 15.3 %, 13.0 % and 12.05 % respectively. The geotechnical properties of the soils are enhanced generally by elevated level of compaction of the soil, thereby achieving the preferred degree of relative compaction required to meet particular

properties of soil (25). MDD greater than 1.45g/cm^3 for basement rocks derived soils according to (25), can be used for landfill liners, therefore all the four soil samples with MDD (figure 10) greater than 1.7g/cm^3 meets compaction test prerequisite making them suitable for liners in landfills. Also (23) recommended a minimum MDD of 1650 kg/m3 or bungalow bricks, indicating that the examined clays are suitable for good rick making materials.

Table 12: Summary of the compaction (ASHTO) Type of compaction

Location	Optimum moisture content (%)	Maximum dry density (kg/m^3)
ERL 1	11.8	1.998
ERL 2	15.3	1.898
ERL 3	13.0	1.942
ERL4	12.05	1.9661

Comparison of Erusu-Akoko clay deposits with some other clay deposits from other parts of Southwestern, Nigeria.

Since the study clay deposits lie in the basement complex of Nigeria, it become imperative to compare some properties such as moulding, firing and strength with some other clay deposits from other parts of Southwestern Nigeria such as Igaran, Imope, Falafonmu and Oke-Oko. It was discovered that the study clay deposits showed similar properties in term of modulus of rupture (367.7psi, 421.29psi), apparent porosity (25.90 %, 26.90 %),linear shrinkage (5.36 %, 5.30%),bulk density (1.50g/cm^3, 1.53cm^3) and water absorption(15.20 %, 16.50%) as shown in table 13.

IV. CONCLUSION

Based on the field relationship, physical inspection, results of the geotechnical analysis, geophysical survey and, geostatistical investigation of the clay deposits carried out in the study area , the clay deposits in Erusu-Akoko can be utilized for the manufacture of ceramics, refractory materials, moulding, bricks production, as a liners in landfills and pottery. If stabilized with lateritic soil of good quality, Erusu clay deposits can also be used for production of both sun-cured and burnt bricks of adequate strength for building construction.

V. RECOMMENDATION

Since different sets of criteria are important to the production of any specific blind for a raw material in industry e.g. in ceramic production,hence, it is therefore imperative, to call for the study of the effect of additive to improve the industrial suitability of these clay deposits. In view of this, I therefore recommend, that Erusu-Akoko clay deposits should be stabilized with additives to improve their industrial suitability. Based on the aforementioned, I hereby recommend a more detail engineering work should be carried out on the Erusu-Akoko, Amo, and Imo Arigidi where large concentration could be located; as well as more detail hydro-geological studies should be conducted to confirm the reason behind the Erusu Akoko, failed Earth dam sited within the clay deposits.

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