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Mineralogy and Geochemistry of Residual clay Formation in Sosan Akoko, Southwestern Nigeria: Implications for Industrial Applications.

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ABSTRACT

Residual clay body overlying Precambrian basement complex in Sosan Akoko, Southwestern Nigeria was studied for its mineralogical and physicochemical characteristics. The aim of the study was to evaluate their industrial potentials and suitability as raw materials. Fifteen representative clay samples were collected from three pits dug in three locations across the study area. The mineralogy and chemical composition of samples was analyzed using X-ray diffractometer (XRD) and inductively coupled plasma-mass spectrometer (ICPMS) techniques respectively while physical analyses include grain size analysis, fired shrinkage, water absorption capacity, loss on ignition, specific gravity and pH. Mineralogical analysis of samples indicates that kaolinite and nontronite are the major clay minerals present while quartz is the major non-clay mineral. Other non-clay minerals include orthoclase, labradorite and albite in lesser amounts. Major element abundances of SiO_2 (ca.58.03%), Al_2O_3 (ca.13.38%) and Fe_2O_3 (ca.7.66%) represent more than 70% of the bulk chemical compositions while CaO, MgO, Na_2O, K_2O, MnO, TiO_2 and P_2O_5 relatively have low values. Detrital orthoclase feldspar, albite and labradorite in the clay samples suggests that it has not yet reached maturity while moderately high ferric oxide imparted a reddish brown colorization. This also supports the presence of nontronite, the iron-rich montmorillonite clay in the sample. Plots of plasticity indices showed that the clay sample is inorganic clay of moderate to high plasticity, compressibility and toughness with the clay-size fraction (<2µm) above 55 %.). Assessment of industrial suitability of the Sosan clay based on the mineralogy, geochemistry, physical properties and the fine nature of the clay and also with appropriate processing which include screening of quartz and iron oxide minerals and bleaching, the clay materials could serve as raw materials for paints, traditional ceramic pots, cosmetics, building bricks and for waste water treatment. The silica sesquioxide and alumina-iron ratio are within the range considered for utilization in the manufacture of good quality cement.

KEYWORDS: Geochemical; Industrial Suitability; Mineralogical; Physical Characteristics; Residual Clay

1. Introduction

Clay is an abundant raw material which has an amazing variety of uses and properties that are largely dependent on their mineral structure and composition. Clay minerals are accumulated products of pre-existing rocks (usually silicate-bearing minerals) occasioned by gradual chemical weathering of low concentrations of carbonic acid and other diluted solvents predominantly in warm tropical and subtropical regions of the world. There are several additional factors which are important in determining the properties and applications of a clay other than the clay structure and composition. These are the non-clay composition, the presence of organic material, the type and amount of exchangeable ions and soluble salts and the texture (Grim, 1950). Clay mineral can also be referred to as a layer silicate mineral (also called phyllosilicate) or other mineral which imparts plasticity and which hardens upon drying and firing (Guggeheim and Martin, 1995). Clay is a rock term and is also used as a particle size term. The term clay has no genetic significance because it is used for residual weathering products, hydrothermally altered products, and sedimentary deposits. However, as a particle size term, the size fraction comprised of the smallest particles which is called the clay fraction. The Wentworth scale defines the clay grade as finer than 4μm (Wentworth, 1922), which is used by many engineers and soil scientists whereas scientists generally consider 2μm as the upper limit of clay size grade. The mixing of certain water proportions with clays enables them with the ability to exhibit plasticity and also slaking. However, clays becomes firm when dry and permanent changes occur physically and chemically when fired in a furnace. This converts the clays into a ceramic material because of these changes. Hence, these properties makes clay useful in pottery making and as decorative and constructive products like bricks, walls and floor tiles. Similarly, clays are used to produce earth wares, stoneware and porcelain when they are mixed with varieties of clay minerals and based on firing conditions. The varieties of clays with different structures and chemical compositions have been discovered in Nigeria. However, many clay deposits in Nigeria still remain unidentified and uncharacterized (Odo and Nwajagu, 2003; Lori *et al.*, 2007) considering the quality and quantity that occur in the country. The underutilization of the clay deposits spread across the country may be ascribed to insufficient geological information on the assessment of their properties as well as shallow knowledge on the appropriate and effective usage of each deposit discovered. Clays have become important materials in modern technology finding applications in ceramics, refractories, paper foundry, rubber, paints, plastics, insecticides, pharmaceuticals, textile and adhesive industries among others. Manufacturing of domestic and commercial wares are sourced largely from clays which underscores their usefulness as raw materials (Dansarai *et al*., 2020; Onyekuru *et al*., 2018; Jongs *et al*., 2018; Adeola and Modupe 2017). Sources of clay deposits in Nigeria include; Ifon, Itu, Kankara, Barkinladi, Ozubulu, Ara Ijero, Orin Ekiti, Onibode, Ijoko, Ibamajo, Ara Ekiti, Eha-alumona, Isan, Ikere, Ezinachi-Okigwe, Jos, Osiele, Enugu, Nkpor and Niger Delta (Ajayi and Agagu 1981; Borode *et al*., 2000, Fasuba *et al*., 2001; Omowunmi, 2001; Elueze and Bolarinwa, 2001; Fasuba, *et al*., 2001; Irabor, 2002; Gbadebo, 2002; Igbokwe and Ogbuagu, 2003; Sullayman and Ahmed, 2003; Odo and Najagu, 2003; Ehinola *et al*., 2009; Olaolorun and Oyinloye, 2010; Akinola and Obasi, 2014; Onyeobi *et al*., 2013; Adeola and Dada, 2017; Onyekuru *et al*., 2018; Jongs *et al*., 2018). These local clay deposits in different part of Nigeria can serve as a good replacement for imported clays for used in metallurgical and other related areas. This can be achieved by establishing proper scientific records of the clays and comparing them with standards, (Dansarai *et al*., 2020). However, the preponderance of these deposits is due to the strategic location of Nigeria within the tropics where the climate is characterized by alternating dry and wet seasons and relatively high humidity allowing intensive weathering. In addition to this, areas of hydrothermal alteration leading to high level of kaolinization have been noted in areas of late Pan African magmatic activity (Okunlola, 2008). Therefore, in response to the challenges that may be posed by the demand for clay materials in Nigeria, indigenous clays with industrial potentials need to be investigated. In view of this, this research work is focused on the physicochemical and mineralogical analyses of a clay body in Sosan Akoko area of Ondo State which is part of the basement complex of southwestern Nigeria, in order to evaluate its industrial potentials.

1.1. Location and Geological Setting

The study area lies within the Precambrian basement complex of Nigeria which is situated within the Pan-African mobile belt of West Africa and Congo Craton. This area falls between latitudes 7° 25´ N to 7° 32´ N and longitudes 5° 53´ E to 5° 58´ E and is accessible by roads and footpaths, (Fig.1). The terrain is gently undulating and few areas of the landscape can be viewed at a glance because of thick vegetation. The three major lithology mapped based on field observation consists of mixed suits of granites, granite gneisses and biotite gneisses. The biotite gneisses occupies the western part of the study area where they form ridges and undulating highland at the west end of the area. The granite gneisses occurs as massive and extensive bodies trending from part of the north-west end and to the north-east end, representing about 50% of the entire study area. They outcropped as domes and high hills. They are leucocratic, medium-coarse grained and are partially weathered. Granites, on the other hand occurs as low lying bodies but partly buried with overburden and covers about 15% of the study area. This area is situated in the tropical rainforest belt of the country.

1.3 Materials and Methods of Study

1.3.1 Sampling and Sample Preparation

Fifteen clay samples were collected from the fieldwork out of which twelve representative samples were subjected to various analyses and tests. The samples were collected from three different locations along a horizontal profile using point sampling method (Fig.2). The different samples collected were put in sample bags and labeled. The samples were subsequently air dried for several days after which they were disaggregated using a rubber headed pestle in an agate mortar.

1.3.2 X-ray Diffraction Analysis

The mineralogical and chemical compositions of refractory clays are best examined and evaluated using the following method: X-ray fluorescence, X-ray diffraction, energy-dispersive X-ray analysis, electron diffraction, differential thermal analysis, infrared spectroscopy and electron microscopy, (Dansarai *et al*., 2020). X-ray diffraction (XRD) studies of the whole rock and clay mount were carried out. The XRD included those for the bulk analysis, the clay fraction, ethylene glycol and heat treated (600^0C) clay fraction. The X-ray diffraction technique is a method used in the study of crystalline materials. It relates physicochemical properties to the crystalline characteristics and helps to identify the minerals present in the sample. Each crystalline substance has its peculiar atomic and molecular structure which diffracts X-ray in a definite pattern. The recognition of a pattern establishes precisely the diffracting substance. The X-ray diffraction analysis is based on passing X-ray beam through a clay sample. The X-ray identifies the structural layers, which is dependent on the d-spacing of the clay mineral. The d-spacing is the exact spacing of the staking of the crystal lattices which indicates the arrangement of the atoms in a mineral. The X-ray on passing through the sample gives peaks that are typical of each type of the minerals that make up the sample. The X-ray beams are diffracted along a group of planes and the way they are diffracted is characteristics of the arrangement of the atoms within the mineral. X-ray diffractograms produced using the Phillips-PW1800 model diffractograms were studied and are for the bulk samples The XRD method is fast and non-destructive. For the purpose of this work, the XRD was carried out at ACME laboratory in Canada.

1.3.3 Chemical Analysis

The ICP/MS technique was used for chemical analysis. The advantage is in the ability of simultaneous multi-element determination over an unusually wide analytical range of elements and to very low detection limits that can be as low as 0.01%. The chemical analysis for this investigation was carried out at the Acme laboratories, Vancouver, Canada. The instrumentation for ICPMS

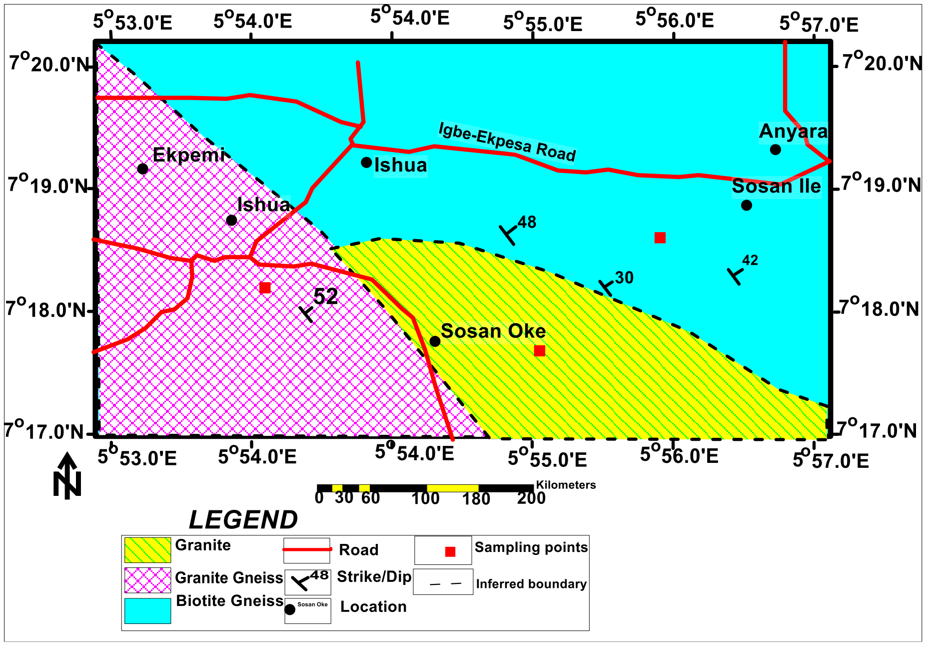

Figure 1: Geological Map of the study area

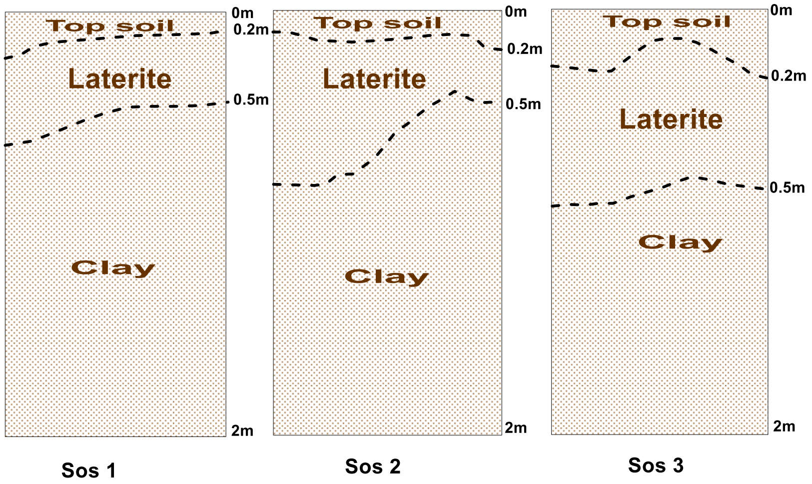

Figure 2: Sampling profile of clay samples from the study area

analysis principally includes the sample introduction system (nebulizer), ICP torch, high frequency generator, transfer optics and spectrometer, and the computer interface. Each samples was introduced into the ICP hardware by aspiration via the nebulizer (the nebulizer transforms the aqueous solution into an aerosol) into a spray chamber. A small fraction of the resulting aerosol was swept by argon into the torch. The torch is situated within a water-cooled coil of a radio frequency generator. As the flowing gases are introduced into the torch, the radio frequency field is activated and the gas in the coil region is made electrically conductive. This sequence of events forms the plasma (a gas in which atoms are present in an ionized state). The ions are extracted from the plasma into a high vacuum (~10-5 torr) region and focused by the Ion Less system. Ions are discriminated from one another according to their mass/charge ratio by the quadrupled mass analyzer and detected by an electron multiplier.

1.3.4 Physical Tests

Plasticity describes the property of clay and other materials to be molded into shapes when mixed with sufficient proportion of water. This behavior in clays is influenced by the particle size and cat-ion exchange capacity of the clay. The point where a material ceases to be plastic and begins to crumble when rolled into a thread, the moisture content at this stage is defined as the plastic limit. Similarly, the moisture content at the stage when the clay mixed with water begins/ceases to flow under standard conditions is known as the liquid limit. The plastic limit and the liquid limit are called Atterberg's limits and are standard tests in soil mechanics. The plasticity index is the range of water content that gives plasticity to a cohesive earthy material. This range lies between the liquid and plastic limits and it is the difference between both

$Plasticity\ index = \ liquid\ limit - Plasticity\ limit$ (1)

1.3.4.1 Liquid Limit Determination

The liquid limit of the clay sample was determined by sieving some pulverized sample using 300-micron sieve. The sieved sample was put on a glass plate and thoroughly mixed with water to form a thick paste. The moisturized sample was transferred into polythene and left for about 12 hours- allowing the grains in the sample to swell to their maximum capacity. It was ensured that all the water added to the sample in the process of liquid-limit determination was available for the sample to flow. A portion of the moisturized sample is transferred into the brass cup of the Cassagrande apparatus (also known as the liquid limit machine device), leveled to the edge of the cup and grooved with the grooving tool. The crank was turned such that the cup raises and drops through about 1cm and the number of blows or strokes are taken at the rate of two blows per second. The number of blows was counted until the two sides of the grooved clay in the brass cup come in contact. Counting between 10 and 50 blows were accepted as valid and recorded. When the groove was closed, a small portion of the wet sample was taken from part of the groove that closed first. This was placed in a small pre-weighed container and weighed. It was then placed in the oven and allowed to dry at 105ºC for 12 hours, after which the dry material was weighed and the percentage moisture content calculated as:

$$\frac{Loss\ in\ weight}{Dry\ weight\ of\ sample} \times 100 \quad (2)$$

Graph of percentage moisture content against the number of blows was then plotted. The percentage moisture content corresponding to 25 blows was taken as the liquid limit for each sample.

1.3.4.2 Plastic Limit determination

A portion of the moisturized sample was mixed on the glass plate until the mass becomes plastic enough to be molded into a ball. This ball was rolled on the grass plate using the palm with just enough pressure, into a ball and rolled again. This procedure was repeated when the clay began to crumble preventing the formation of the thread. This point marks the plastic limit. A portion of the crumbled sample is placed in a can for moisture content determination. Both plastic and liquid limit are expressed as a percentage by weight of the over-dried sample. At moisture contents between the two limits, the soil is in a plastic state so that the arithmetic difference between the two values, known as the plasticity index.

1.3.4.3 Linear Shrinkage Determination

The linear shrinkage test is to determine the behavior of the clay and to what extent it will shrink under certain conditions. Some of the samples used in liquid limit determination were also used. For linear shrinkage, the sample is taken when the amount of moisture contained is a little more than the liquid limit level. Samples were taken when the number of blows is between 16 and 22. The liquid limit is at 25 blows. The sample taken is used to fill a waxed linear shrinkage mould and placed in the oven set at 105º for 12 hours. The 127mm length mode was used in this work. The new length of the clay in the mould after oven drying was measured and the difference in length before and after drying was recorded. The percentage linear shrinkage was determined as follows:

$$\frac{Change\ in\ length}{127} \times 100 \ (3)$$

The behavior of the clay in terms of shape is also described. It either remains straight or is bent to different extent.

1.3.4.4 Particle Size Analysis

The method of analysis used in this study for the determination of the particle size distribution was the 'Wet Sieve Analytical method'. The method was used for sizes coarser than 63 microns. One hundred grams of each sample were weighed, air dried and soaked with distilled water in aluminum basins for twenty four hours to allow for thorough dispersion of the clay components. The slurry was poured into moulinex food mixer and the mixture was blended for few minutes to enhance further dispersion. Sieves of 4.75mm, 2.36mm, 850µm, 425µ, 300µm, 150µm, 75µm and 63µm were stacked together with a metallic pan at the bottom of the arrangement. The prepared slurry was poured through the sieves. All materials that were less than the 4.75mm sieve were washed through the sieve by squinting water gently brushing with a sieve brush. The materials left on each sieve were dried, weighed and recorded. This was done for all sieves from 4.75mm to 63 micron size one after the other. The residue collected in the metallic container at the end of each process was transferred into a beaker and allowed to settle down and the water on top of the residue was decanted avoiding less of the materials. The residue was dried in the oven at a temperature of 110ºC and stored for further examination.

1.3.4.5 Firing Test

Clays, in practice are fired to a sufficiently high temperature for incipient glass formation to bind the particles into a strong and mechanically resistant mass. The physical manifestation of incipient glass formation is a shrinking of the clay termed ‘firing shrinkage’. The degree of firing depends on the fluxing oxides and the state of subdivision of the materials in which they are combined. The chief fluxes are the alkalis (K_2O and Na_2O. Lime (CaO), magnesia (MgO) and ferric oxide (Fe_2O_3). Firing affects the strength, hardness, permeability, density, pore structure and color of the clays. Pressed powder pellets of raw samples (7gm of clay samples) were prepared with a pressure gauge of 15 tons on a ram. Representative pellets of each sample was subjected to preliminary ceramic tests which included firing at temperature range from 200ºC to 1200ºC to identify the firing range and color changes. Quick firing of another set of pellets is carried out to determine the bloating characteristic. The samples were first dried and ground to pass 250 micron sieve and then pressed into powder pellets. The first set of pelletized samples was fired directly at 1200ºC in the carbolite furnace. After firing for two hours, the furnace was allowed to cool down to room temperature and the pellets were cooled in a desiccator and weighed. The difference between the dry diameters and the fired diameters of the pellets give the shrinkage which is expressed as percentage of dry diameters of the pellets. Several other pellets were fired at different temperatures of 1000ºC, 1100ºC and 1200ºC so as to ascertain or determine the variation in properties with increased temperature.

1.3.4.6 Water absorption determination

Water absorption is a measure of readiness with which fluid passes through a solid and is of obvious importance in building products in connection with the ease of penetration of rain and ground water. It is a common method of expressing porosity value of common building and engineering bricks and some tiles. Direct fired pellets were placed on a furnace at 1100ºC allowed to cool in a desiccator weighed and completely immersed in water at room temperature. At 24 hours of immersion, they were removed, wiped with a damp cloth and weighed again. The difference between the weighing gives the water absorption after 24 hours in cold water. Water absorption is expressed as percentage of the original weights of the pellets.

1.4 Results and Discussion

1.4.1. Clay Mineralogy

The X-ray diffractograms of the studied Sosan clay is presented in figures 3, 4 and 5 respectively. The mineralogical data revealed that the clay is composed of nontronite, an iron-rich montmorillonite clay of the smectite group and Kaolinite as the major clay minerals. The diffractograms also showed the abundance of quartz in the sample as the major non-clay mineral with minor amount of orthoclase and labradorite as well as albite. Conspicuous kaolinite peaks reflected at 7.13A, nontronite 15.76A, Quartz peaks are identified at 4.2A, 3.33A and 1.81A as indicated in figures 3, 4 and 5respectively.

1.4.2 Geochemical Composition

Major element abundances of calculated average values for SiO_2 (58.03%), Al_2O_3 (13.38%) and Fe_2O_3 (7.66%) represents more than 70% of the bulk chemical compositions (Table 1) while CaO, MgO, Na_2O, K_2O, MnO, TiO_2 and P_2O_5 have lower values. The high value of Fe_2O_3 (7.66%) is in likelihood due to tropical weathering and the lateritic horizon overlying the clay samples (Figure 2). the K_2O average composition of 2.72% indicates that feldspar has not been intensely weathered. The CIA and CIW values of 76.02% and 89.9% respectively suggests a felsic source and also implies a recycling process (Nesbitt *et al.,* 1980). These indexes value indicates high (intensive) weathering of the source rocks as reported by Fedo, *et al.,* 1995 and McLennan, 1993 that the CIA and CIW values greater than 70% indicates weathering that is intensively high either at the source or during transportation before deposition. The plots of SiO_2 against $Na_2O + K_2O$ of the clay samples revealed that the clay weathered from falls within the zone of basaltic andesites and andesites rocks (Fig.6). The plot of SiO_2 and K_2O variations which was based on the classification by Taylor, (1990) indicated that the clay samples/minerals falls within the zone of high-K Calc-Alkaline series (Fig.7). The presence of detrital orthoclase feldspar, albite and labradorite (rock-forming minerals) as revealed in the mineralogical data suggests that the clay samples has not yet reach maturity. Moderate chemical conditions are favorable for smectite mineral generation as it is evident in the low kaoloinite and smectite clay minerals present in the study area.

1.4.2.1 Comparison and evaluation of the industrial potentials of Sosan clay in terms of its chemical composition.

The comparison of Sosan clay with some reference samples and industrial specifications is presented in Table 2. Compared with notable clays, the average SiO_2 content compared favorably with Florida active clay (Huber, 1985) and plastic fire clay St. Louis (Huber, 1985). The alumina content is very low compared to the China and plastic fire clay but higher than Florida active clay. The average percentages of (Na_2O+K_2O), Fe_2O_3 and MgO are higher than China clay, Florida active kaolinite and fire clay St. Louis (Huber, 1985) while the CaO compares favorably with plastic fire clay.

1.4.2.2 Industrial Evaluation in terms of Chemical Composition

Assessment of the industrial potentials of the studied clay in terms of chemical composition is presented in Table 2. The very low alumina content of ca. 13.38 wt. % compared with refractory standards of 25-40 wt. % for alumina, coupled with high iron oxide of ca. 7.66 % and organic matter make the sample unsuitable as refractory material. The corresponding values of CaO, MgO and Na_2O in the clay are lower than what is required in the manufacturing of brick clay (Murray, 1960). However, K_2O content of the studied clay is similar to brick clay. The clay will require blending with lime so as to raise the percentage of CaO in order to meet up with industrial specifications for brick clay. In addition, a comparison of the chemical composition of the clay with those specified for some industrial clay showed that the amounts of Na_2O, K_2O, MgO, CaO and Fe_2O_3 in the samples are higher than what is required in production of paints. However, appropriate processing technique may significantly improve the quality of the clay body. The silica-sesquioxide ratio (S.R.) has an average value of 2.76, while the average value for alumina-iron ratio (A.R.) is 1.75. These ratio values are within the ranges of 1.5 to 4.0 and 1.4 to 3.5 respectively considered for clay or shale suitability for utilization in the manufacture of good quality cement (Abatan *et al*., 1993).

1.5 Physical characteristics

1.5.1 Grain size analysis

It is not sufficient merely to quote a limiting size range in order to assess fully the relative fineness of clay minerals because many different sizes exist in any one mineral. Hence, it is clearly better to determine the percentage material whose particles lies within certain narrow limits i.e. size distribution. A variety of methods including electron microscopy, sedimentation techniques, surface measurements and gas absorption are used in particle size analysis. However, sieve analysis and hydrometer analysis were employed for the particle size measurement in this study.

The results of the grain size analysis are presented in (Table 3) while figure 8 shows the average grading curve of Sosan clay. The amount of fine in the samples ranges from (63-66%) and the percentage of clay size particles between 50-53%, Silt 10-15% and sand 34-38% is presented in Table 4. The grading curve indicates well graded sandy clay.

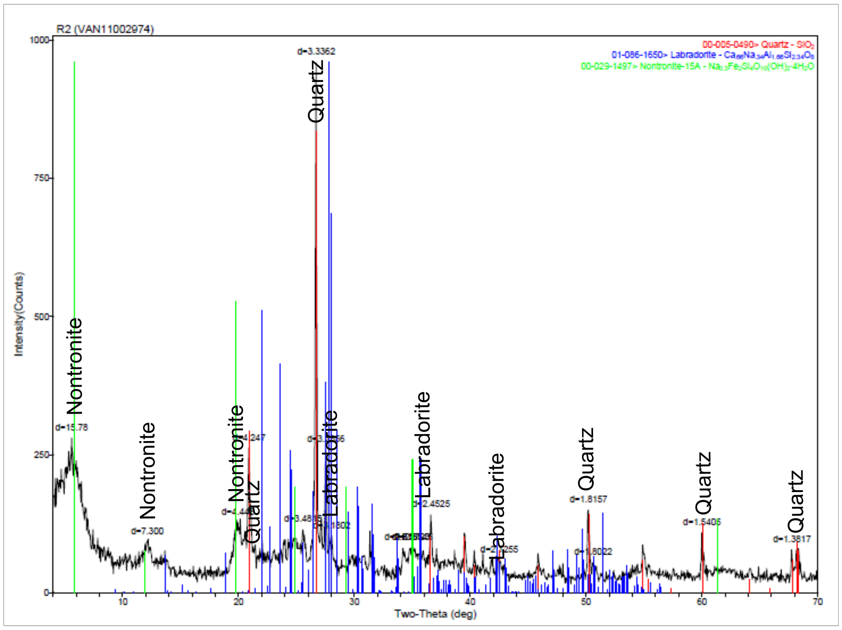

Figure 3: Diffractogram of the whole rock sample of SOS 1

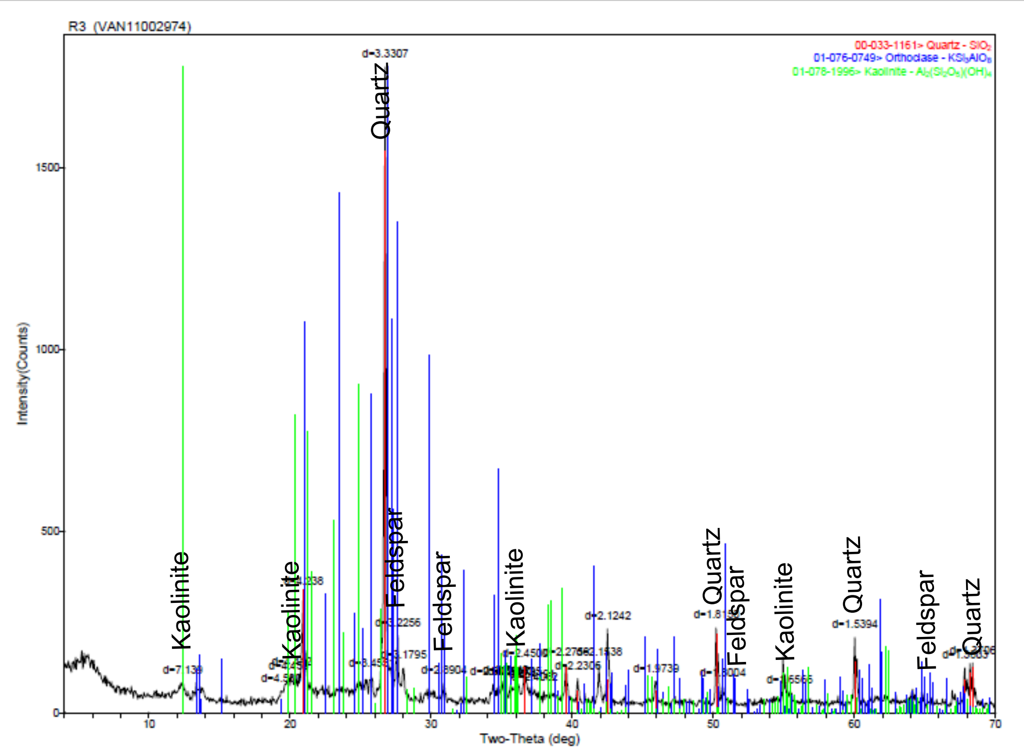

Figure 4: Diffractogram of the whole rock sample of SOS2

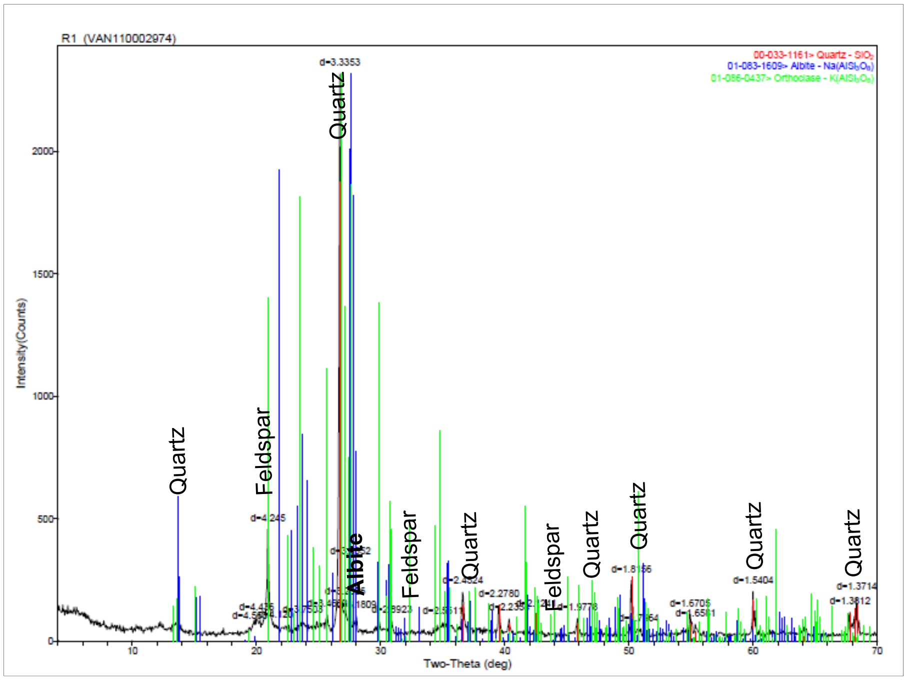

Figure 5: Diffractogram of the whole rock sample of SOS3

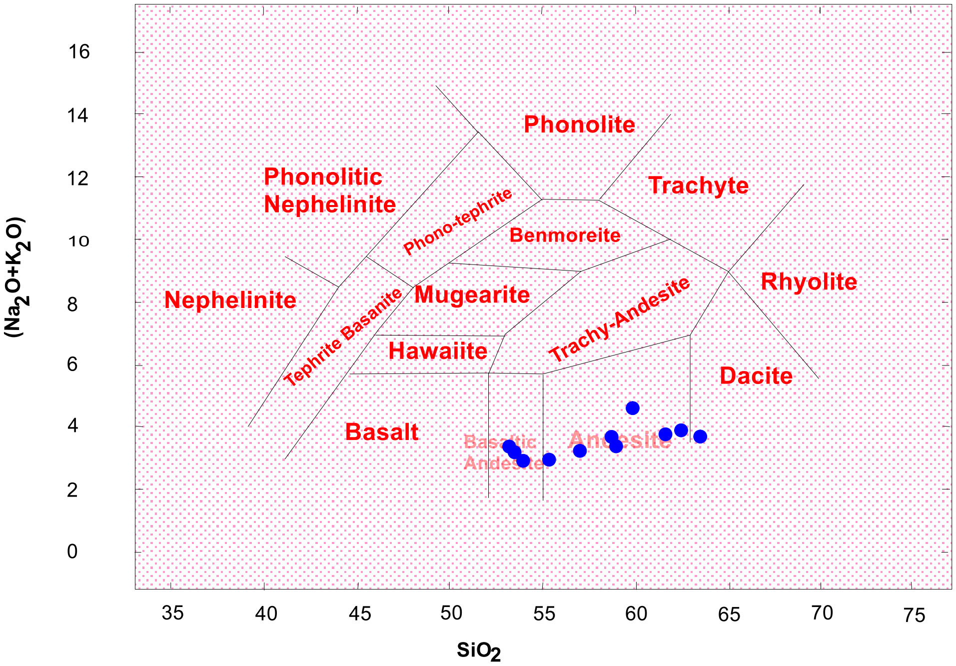

Figure 6: Discrimination diagram of the clay samples

1.5.2 Atterberg limit tests

The Atterberg limit results are presented in Table 5. Liquid limit (LL), plastic limit (PL) and plasticity index (PI) values ranges from (48.5-57.2 %), (21.7-32.9 %) and (18.7-27 %) respectively. The clays exhibit moderate to high plasticity (LL < 5 % LL > 5 %) which is probably due to the low percentage of sand particles and the presence of significant amounts of expandable mixed layer clays, smectite group of clay minerals as revealed from the mineralogical analysis (Fig.3,4 and 5) and/or organic matter. Plot of plasticity index values versus the liquid limit value were made for the clay sample on the Casagrande (1948) plasticity chart for the classification of cohesive soils. It was observed from this plots that, all the clay samples falls within the region of moderate to high toughness and compressibility. The clay bodies are inorganic clay of medium to high plasticity above A-line as revealed from the chart (Fig. 9). Similarly, Bain (1971), proposed a clay classification chart on which various fields of clay mineral types can be distinguished using the plastic limits and the plasticity index as the basic parameters. However, on this basis, Sosan clay samples plot within the field of kaolinite. These facts confirm that these clays originated from the weathering of igneous and metamorphic rocks of the basement complex.

1.5.3 Fired shrinkage

The shrinkage values (Table 6) for the clay are relatively high (5.7 to 6.6 %). This is probably due to high percentage of fine particles present in the clay materials and the presence of expandable clay mineral in the sample, which may lead to the transformation of kaolinite to illite and possibly montmorillonite as a result of excessive hydration. Percentage shrinkage generally increases with temperature, until vitrification is fully attained. Vitrification is as a result of fusion, which generates liquid that fills up the pore spaces in the clay. The relatively high shrinkage may to some extent lead to warping and cracking during firing of the clay. However, the shrinkage value falls within the acceptable limit of not more than 30% recommended for clays used for the manufacturing of burnt bricks.

1.5.4 Firing characteristics

The fired color of clay is very essential in its utilization for ceramics and refractories. The fired color characteristics of the clay samples is presented in Table 7 while Fig.10, showed the fired pellets. All the samples exhibited color changes when fired at a temperature of 1200ºc. Two groups of fired colors were obtained which are moderate reddish brown and moderate yellowish brown colors. These firing colors are dependent on the amount of the oxides of iron and titanium. The reddish/yellowish brown fired colors are probably due to high content of iron and organic matter in the clay samples (Table 7). This reddish/brownish colorization is preferred in pottery and brick industries.

1.5.5 Water absorption capacity

Water absorption was determined as the percentage of water absorbed, when sample pellets were completely immersed in water for 24 hours. The values for WAC ranges from 11.18-12.7% (Table 7). These high values could be attributed to high percentage of fine materials in the samples. This further suggests a high porosity and permeability in the clay sample. Clay mineralogy plays a significant role in porosity apart from the grain size, shape and packing. Water absorption capacities are usually higher in clay samples that contain montmorillonite and vermiculite because of the expanding lattice of such clay minerals. The swelling potential of montmorillonite and vermiculite are therefore very high.

1.5.6 Loss on ignition

Loss on ignition (LOI) is a measure of the constitutional water in the clay samples. The clay pellets were initially dried in the oven at 110ºC for 24 hours. Loss on ignition (LOI) was determined on dried specimens as percentage weight difference between the fired and unfired samples at 1200ºC. Average values and ranges of LOI obtained for samples pellets from the various weathering profile established is presented in Table 1, ranging from 8.9-14.6 % with an average of 11.9wt %. These values are slightly higher compared with those obtained from similar residual clay bodies in other part of southwestern Nigeria (Bolarinwa, 1992; Elueze and Bolarinwa, 1995; Elueze and Bolarinwa, 2001. However, they fall within the limit of (6-18 wt %) for clay minerals (Chesti, 1994).

1.5.7 Specific gravity

The samples are generally dense with specific gravity (SG) ranging from 2.72-2.77 (Table 8). It further shows that a similarity exists in the SG values of the studied clays. The relative closeness in the values suggests that the clay samples have

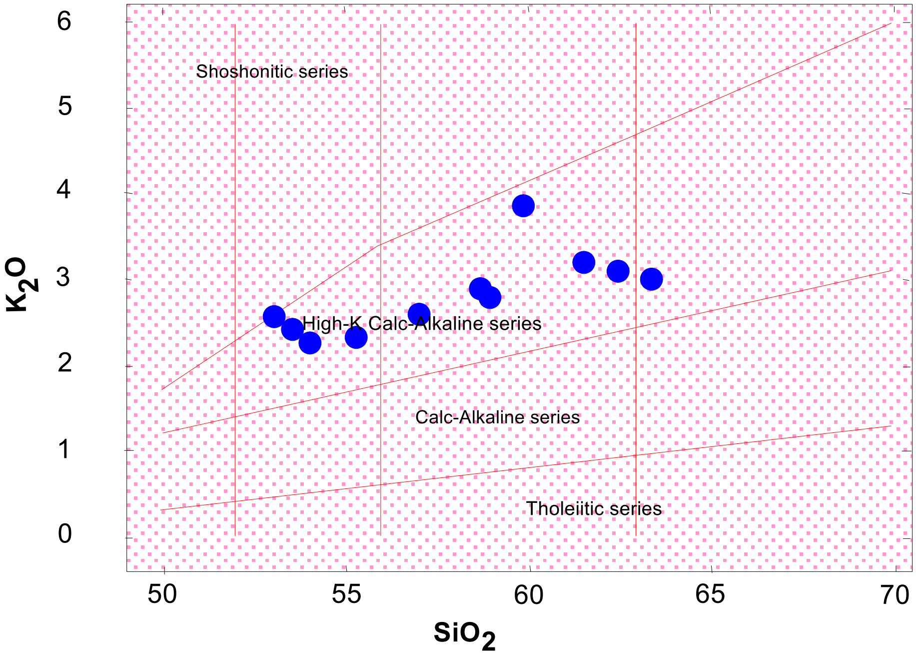

Figure 7: Relationship between SiO_2 and K_2O content

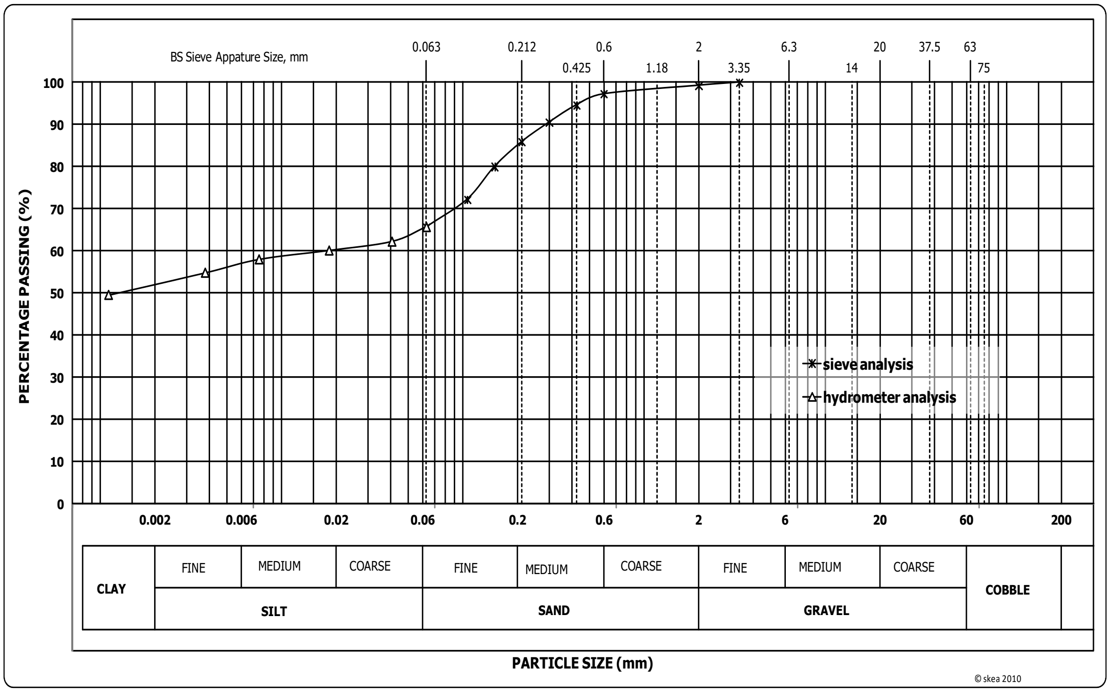

Figure 8: The average curve of Sosan clay

similar mineral composition and tends to agree with Shekoor and Brock (1987) submission that to some extent, S.G is useful in comparing the mineralogy of studied samples.

1.5.8 PH

The PH value of the studied clay sample ranged between 4.7- 5.3 as shown in Table 8, which

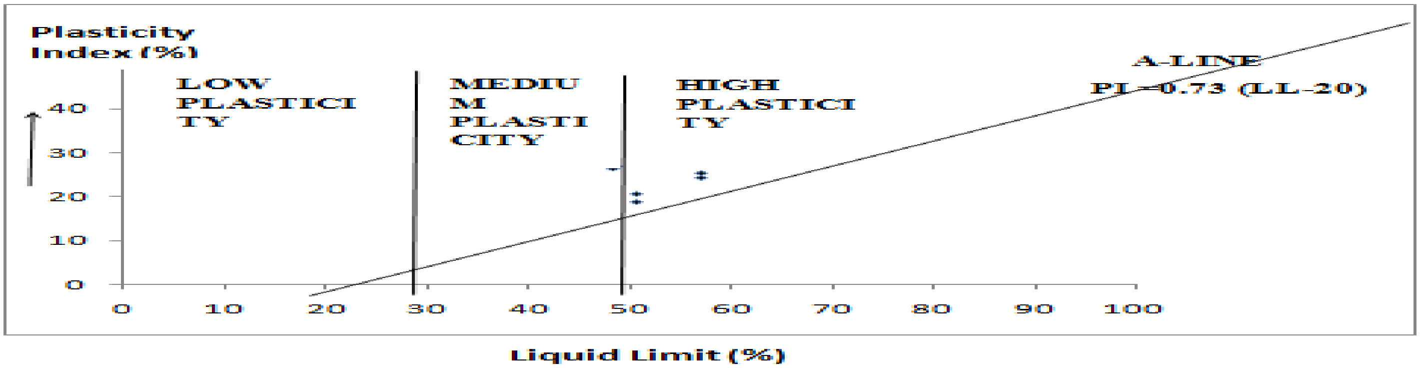

Figure 9: Plasticity chart for the classification of the Sosan clay (after Cassagrande, 1948)

Fig. 10: Colour change of clay samples before (a,b,c,d,e,f) and after firing (A,B,C,D,E,F)

suggested that the Sosan clay was formed under a slightly acidic environment.

1.6 Conclusion

Field investigation of the Sosan clay indicates that the clay body is as a result of *in situ* weathering of biotite gneiss, granite gneiss and granite. Mineralogical composition based mainly on X-ray diffraction studies confirms that the clay is dominated by Nontronite and Kaolinite while quartz is the major non-clay mineral present. Orthoclase and Labradorite are present in minor amounts as well as albite. Major element abundances of SiO_2 (ca.58.03%), Al_2O_3 (ca.13.38%) and Fe_2O_3 (ca.7.66%) represent more than 70% of the bulk chemical compositions while CaO, MgO, Na_2O, K_2O, MnO, TiO_2 and P_2O_5 relatively have lower values. The presence of moderately high ferric oxide imparted a reddish brown colorization. This also supports the presence of Nontronite, the iron-rich montmorillonite clay. The high values of Rb and Zr indicate the presence of felsic rocks. The pH of 4.7 to 5.3 practically indicates a chemical decomposition in an essentially slightly acidic environment. On the basis of physical parameters, plots of plasticity indices showed that the clay sample is inorganic clay of moderate to high plasticity, compressibility and toughness with the clay-size fraction (<2µm) above 55%. This is due to the greater concentration of the fine clay-size materials and Nontronite. The shrinkage values are relatively high (ca.6.31%) and the loss on ignition (ca. 11.9%). Adequate mouldability characterizes the clay with an acceptable firing color of reddish brown and yellowish brown. The clay-sized body is very dense with an average specific gravity of ca. 2.7. The mineralogical, chemical and physical characteristics of these residual bodies showed they are amenable to beneficiations. For instance, the removal of the non-clay fractions and gritty content could upgrade the clay. Similarly, chemical treatment of Fe_2O_3 through leaching method and other impurities could enhance the Al_2O_3 content and depreciate SiO_2 abundances (Elueze *et al*, 2004). Assessment of industrial suitability of the Sosan clay based on the mineralogy, geochemistry, physical properties and the fine nature of the clay and also with appropriate processing which include screening of quartz and iron oxide minerals and bleaching, the clay materials could serve as raw materials for paints, traditional ceramic pots, cosmetics, building bricks and for waste water treatment. The silica sesquioxide and alumina-iron ratio are within the range considered for utilization in the manufacture of good quality cement.

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Table 1: Average chemical composition (weight %) of Sosan clay

Oxides (%)	**Mean (%)**	**Range (%)**
SiO_2	58.03	53.10-63.40
Al_2O_3	13.38	13.72-17.22
Fe_2O_3	7.66	7.15-8.00
MnO	0.04	0.04-0.05
MgO	0.83	0.55-1.12
Na_2O	0.70	0.67-0.72
K_2O	2.72	2.31-3.19
TiO_2	1.50	1.35-1.67
P_2O_5	0.03	0.02-0.04
CaO	0.80	0.66-0.92
LOI	11.84	8.90-14.60
CIA	79.43	73.5-81.1
CIW	90.84	88.1-91.6
RBL	2.65	2.45-3.40

Major elements as weight percentage (wt.) %. Total Fe as Fe_2O_3, CIA= [Al_2O_3/ (Al_2O_3 + CaO + Na_2O + K_2O)] X 100, CIW= [Al_2O_3/ (Al_2O_3 + CaO + Na_2O)] X 100 in molecular proportions. Relative base loss (RBL) = Al_2O_3/CaO+MgO+NA_2O+K_2O and TIO_2/Zn X 100. S.R = 2.76, A.R = 1.75, Na_2O + K_2O = 3.42, CaO + MgO = 1.63

Table 2: Comparison of average clay values in the study area with some industrial specifications

		REFERENCE SAMPLES			**SOME INDUSTRIAL SPECIFICATIONS**			
Oxides	Average for studied clay (%)	A %	B %	C %	(1) %	(2) %	(3) %	(4) %
SiO_2	58.03	46.88	52.92	57.67	48.67	67.50	51.0-70.0	45.30-47.90
Al_2O_3	13.38	37.65	9.42	24.00	9.45	26.50	25.0-44.0	37.90-38.40
Fe_2O_3	7.66	0.88	3.65	3.32	2.70	0.50-1.20	0.5-2.4	13.40-13.80
MnO	0.04	-	-	-	-	-	-	-
MgO	0.83	0.13	0.08	0.30	8.50	0.10-0.19	0.20-0.70	0.20-0.30
CaO	0.80	0.03	1.91	0.70	15.84	0.18-0.30	0.10-0.20	0.03-0.25
Na_2O	0.70	0.21	0.03	0.20	2.76	0.20-1.50	0.80-3.50	0.20-0.35
K_2O	2.72	1.60	0.98	0.50	2.76	1.10-3.10	-	0.10-0.40
TiO_2	1.50	-	1.18	-	-	-	-	45.30

A = China Clay (Huber, 1985)
B = Florida active kaolinite (Huber, 1985)
C = Plastic fire clay, St. Louis (Huber, 1985)
(1) = Brick clay (Murray, 1960)
(2) = Ceramic (Singer and Sonja, 1971)
(3) = Refractory bricks (Parker, 1967)
(4) = Paints (Paynes, 1961)

Table 3: Grain size distribution

Diameter	Sos 1a	Sos 1b	Sos 2a	Sos 2b	Sos 3a	Sos 3b	Average % passing
3.350	100	100	100	100	100	100	100
2.000	99.2	99.5	99.5	99.5	99.2	99.2	99.35
0.600	97.2	97.5	98.7	97.6	97.7	97.7	97.73
0.425	94.6	94.9	95.8	94.8	94.7	95.7	95.08
0.300	90.5	90.2	91.7	90.7	90.3	91.3	90.78
0.212	85.9	85.6	87.4	85.6	84.0	85.1	85.60
0.150	80.0	79.1	81.1	79.3	78.3	78.5	79.38
0.106	72.2	70.2	72.8	70.2	71.9	72.1	71.57
0.063	65.6	64.1	63.0	62.2	63.7	64.9	63.92
0.0573	63.19	62.38	62.41	60.49	61.64	63.08	62.20
0.0407	62.14	61.34	61.35	59.47	60.63	62.06	61.17
0.0183	60.03	59.26	59.23	57.42	58.61	60.03	59.10
0.0075	58.98	58.22	57.12	55.37	56.59	57.99	57.38
0.0038	54.77	53.02	55.00	52.29	54.57	54.94	54.10
0.0027	52.66	50.94	52.89	50.24	52.55	52.91	52.03
0.0011	49.50	47.82	50.77	48.19	50.53	50.87	49.61

Table 4: Some physical properties of the Sosan clay

Sample code	Clay %	Silt %	Sand %	PI %	% fine
SOS 1a	52	14	34	32.2	66
SOS 1b	50	15	35	31.6	65
SOS 2a	53	10	37	21.7	63
SOS 2b	50	12	38	22.2	62
SOS 3a	53	11	36	32.9	64
SOS 3b	53	12	35	32.7	65

Table 5: Atterberg limit result

SAMPLE CODE	LL %	PL %	PI %
SOS 1A	50.9	32.2	18.7
SOS 1B	50.8	31.6	19.2
SOS 2A	48.7	21.7	27.0
SOS 2B	48.5	22.2	26.4
SOS 3A	57.2	32.9	24.3
SOS 3B	57.2	32.7	24.5

Table 7: Firing characteristics

SAMPLE CODE	Color before firing	Color after firing	Fired shrinkage (%)	WAC (%)
SOS 1a	Moderate brown	Moderate reddish brown	5.7	11.73
SOS 1b	Moderate brown	Moderate reddish brown	6.6	11.43
SOS 2a	Moderate brown	Moderate yellowish brown	6.3	12.50
SOS 2b	Moderate brown	Moderate yellowish brown	6.3	12.79
SOS 3a	Moderate brown	Moderate reddish brown	6.5	11.24
SOS 3b	Moderate brown	Moderate reddish brown	6.5	11.18

Table 8: pH and specific gravity of Sosan clay

Sample code	pH	S.G
SOS 1a	4.8	2.74
SOS 1b	4.7	2.73
SOS 2a	5.3	2.72
SOS 2b	5.2	2.73
SOS 3a	4.8	2.76
SOS 3b	4.9	2.77