International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 2, Issue 7 (May 2013) PP: 20-26

Chemical and Mechanical Characterization of Clay Samples From Kaduna State Nigeria

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ABSTRACT: *This research investigates the chemical and mechanical characteristics of clay samples from Kaduna State in Nigeria with a view to determining them for industrial applications. Three different clay locations were selected for investigation namely Kachia, kafanchan and Wusasa. The clay specimen were collected from fifteen cites in each location for better representation of the location. The samples so collected were mixed properly and a representative specimen for test from that location was produced using the cone and quartering system as recommended by the American Society of Testing Materials (ASTM). Atomic Absorption Spectrometer(AAS) was used to determine the chemical composition, while other established processes were used to determine the mechanical properties like particle size distribution, specific gravity, bulk density, solid density, water absorption, apparent porosity, permeability to air, refractoriness, thermal shock resistance, modulus of rupture, linear shrinkage and thermal conductivity. The chemical analysis showed that all the samples had high percentages of silica and alumina, thereby classifying them as Alumino-silicates.*

The values for specific gravity, bulk density, solid density and apparent porosity averaged 2.62, 1.933g/cm^3, 2.86 g/cm^3, and 13% respectively and they were within the internationally accepted range. The values for linear shrinkage, permeability to air and thermal shock averaged 8.72%, 71.1, and 29+ respectively and these also were within the accepted limits. The values for modulus of rupture and thermal conductivity averaged 88.7 MN/m^2 and 0.516W/m^{o}K. The refractoriness of all the samples were >1300^{o}C and this showed that they could be used as industrial products.

Key words: *Chemical, mechanical, characterization, clay, samples, Kaduna State*

I. INTRODUCTION

Clay is an abundant raw material. However, certain high grade types of clay deposits are limited in geographic occurrence and extent.

Clays containing a preponderance of the clay mineral kaolinite are known as kaolinitic clays. Several commercial clays are composed predominantly of kaolinite. These are China clays, kaolines, ball clays, fireclays, and flint clays. The terms China clay and kaolin are used interchangeably in industry. Akinbode (1996)

China clays are high grade white kaolins found in the Southeastern United States, England, and many other countries. In Georgia and South Carolina, the largest producing states, the deposits are composed almost wholly of the mineral kaolinite and occur as lenticular-shaped bodies generally 1.8-7.5m in thickness. Mahmoud et al(2003) Many grades of kaolin are used in the manufacture of ceramics (whitewares, refractories, and porcelain), paper, rubber, paint, plastics, insecticides, adhesives, catalysts, and ink. They are also used for many other industrial purposes McGraw-Hill (1977).

Kaolin has the desirable properties of being white in color, very fine in particle size, nonabrasive (hardness 2-2.5 on mohs scale), and chemically inert in most uses. The individual kaolin particle is a thin, flat, pseudohexagonal platelet, so tiny that approximately 10,000,000 spread on a postage stamp would form a layer thinner than the thickness of a human hair. Oaikhinan(1988) This thin, flat particle shape is a distinct advantage in many uses. The grade of kaolin that are commercially available generally are based on particle size and on colour, or brightness. In whitewares and sanitary wares, kaolin provides a white body, gives easy molding properties, and adds strength, dimensional stability, and smooth surfaces to the finished product. Refractoriness, dimensional stability and chemical inertness make the kaolins uniquely suitable for special refractories. In addition to the above properties, the excellent dielectric properties of kaolin are very suitable for porcelain electric insulators. Olusola (1998)

Those clays that are composed mainly of the clay mineral montmorillonite and are formed by the alteration of volcanic ash are known as bentonites. They are used in many industries; the most important uses are as drilling muds and catalysts in the petroleum industry, as bonding clays in foundries, as bonding agents for taconite pellets, and as adsorbents in many industries. Ahmed(1986)

The largest producing areas of bentonite are Northeastern Wyoming, Western South Dakota, central and Eastern Texas, and Northeastern Mississippi Grimshaw (1959).

Bentonites are used in the foundry industry to bind sands into desired shapes in which metals can be cast. Only 3-5% bentonite is needed to bond the sand grains together. Because of their fine particle size and the nature of their water adsorption, bentonites give the mold a higher green, dry, and hot strength than does any other type of clay. A rapidly increasing use of bentonite as a bonding agent is in the taconite industry. Manukaji (2004)

Refractories are used in metal melting and heat treatment industries because of their high temperature operating conditions. It is also used in industries both as lagging and insulating material. They degenerate with time and therefore need replacement. If the industries that use them are to remain in business, replacement must not only be produced but also must be locally sourced.

Technological development in Nigeria led to the development of iron and steel industries together with other industries that utilize refractories. For instance the Ajeokuta steel complex in Nigeria on completion will require about 3600 tones of refractory bricks worth over N22 million Abifarin (1999). Similarly electric cooker, oven and furnace manufacturing industries use refractories as their major assembling materials. These refractories are presently being imported and cost the manufacturers about N3.95 million. Also other steel rolling mills in Nigeria will consume about N4.5 million worth of refractories when fully operational Abifarin (1999).

II. METHODOLOGY

The test samples were collected from fifteen different locations on a particular area in order to have a good representation of the sight. Three areas were used for the state in order to further give a wider sample spread for the state. The areas are

KADUNA STATE, NIGERIA: Kachia, Kafanchan, Wusasa

The samples from the fifteen locations on an area were mixed properly and a representative specimen for test from that area was produced using the cone and quartering system as recommended by the American Society of Testing Materials (ASTM). The process involves mixing the samples and spreading them uniformly and equally into a rectangle. The rectangle is divided into four equal parts and two alternate portions were taken, mixed properly and formed into a cone. The cone was also divided into four equal parts while the alternate portions were further taken. This process of mixing properly, spreading into rectangular shapes and cones and taking the alternate portions continued until a sizable quantity sufficient for the tests to be carried out were produced.

The resultant specimen for each area were kept in a P.V.C. bags and labeled as follows.

LOCATION	**SPECIMEN LABEL**
Kachia	**M**
Kafanchan	**N**
Wusasa	**O**

COLOUR INSPECTION

The specimen were physically inspected for colour appearance and the following results as shown below were observed.

SPECIMEN	**COLOUR**
M	Creamy Yellow
N	Chocolate white
O	grayish

III. SIEVE TESTING

Each specimen was milled down using a hammer mill, soaked in water for 48 hours after which, it was dried by spreading it on a tray in the sun. 600g of each specimen were sieved using 700µm, 500µm, 300µm, 100µm, 50µm sieves on a mechanical vibrator for 30 minutes after which the content of each sieve was weighed. The mass of the specimen left at each compartment of the sieve, the percentage retained and the percentage passed were calculated and the results were produced in the table below

TABLE 1: SIEVE ANALYSIS

CLAY SPECIMEN	Sieve no in µm	Mo	M1	%R	%P
SPECIMEN M	700	600	27.28	4.55	95.45
	500	600	106.31	17.72	82.28
	300	600	273.27	45.55	54.45
	100	600	98.52	16.42	83.58

	50	600	77.72	12.95	87.05
SPECIMEN N	700	600	37.23	6.21	93.79
	500	600	97.98	16.33	83.67
	300	600	291.02	48.50	51.50
	100	600	88.51	14.75	85.25
	50	600	76.78	12.80	87.20
SPECIMEN O	700	600	28.71	4.79	95.21
	500	600	108.88	18.15	81.85
	300	600	283.52	47.25	52.75
	100	600	97.06	16.18	83.82
	50	600	71.73	11.96	88.04

IV. CHEMICAL ANALYSIS

In determining the chemical constituents of the specimens, The Atomic Absorption Spectroscopy method was used. In this process, the instrument was calibrated while solutions of the specimens were prepared.

One gramme of each of the various specimens were dissolved in 10 mililitres of sulphuric acid. After proper stirring, the solution was evaporated and the deposits were still dissolved in 10 mililitres of sulphuric acid. It was then filtered. Small quantities of the filtrates were collected, diluted and atomic absorption spectroscopy was used to determine each constituent by the use of air acetylene flame.

Also 10g of each dried clay specimen was cooled using a desiccator. A crucible was weighed empty and later weighed together with each clay specimen. The crucible and its content were heated in an electric furnace to about 800^{o}C and allowed to cool in a desiccator. The crucible and its content were weighed again. After the experiment, the loss of ignition were then calculated and the results were as follow

TABLE 2: CHEMICAL ANALYSIS

Oxides in Specimen	Specimen in Percentages		
	M%	N%	O%
SiO_2	41	40	44
Al_2O_3	35	42	36
Fe_2O_3	0.6	0.7	0.9
TiO_2	3.8	1.0	1.4
CaO	0.4	0.3	0.5
MgO	0.3	0.3	0.7
K_2O	2.2	1.4	2.3
Na_2O	0.7	0.3	0.2
L.O.I	16	14	14

FURTHER TESTS:

Further tests were carried out using the standard instruments and methods and the results obtained are shown below

TABLE 3: SPECIFIC GRAVITY

Clay specimen	**M**	**N**	**O**
Specific Gravity	2.69	2.59	2.58

TABLE 4: BULK DENSITY

Clay specimen	**M**	**N**	**O**
Bulk density g/cm^3	1.98	1.87	1.95
Solid densityg/cm^3	2.93	2.95	2.69

TABLE 5: LINEAR SHRINKAGE

Clay specimen	**M**	**N**	**O**
% average drying shrinkage	2.22	2.17	2.04
% average firing shrinkage at 1200°C	9.09	8.17	8.91

TABLE 6: PERCENTAGE WATER ASORPTION

Clay Specimen	**M**	**N**	**O**
% water absorption at 110°C	29.7	30.2	33.7
% water absorption at 1200°C	3.1	3.0	3.7

TABLE 7: APPARENT POROSITY

Clay specimen	**M**	**N**	**O**
% apparent porosity at 110°C	25	23	20
% apparent porosity at 1200°C	14	13	12

TABLE 8: PERMEABILITY

Clay Specimen	**M**	**N**	**O**
Permeability	68.1	71.2	73.9

V. REFRACTORINESS

Test cones were prepared from each clay specimen, dried and placed in a furnace along with pyrametric cones designed to deform at 1000 , 1300, and 1500°C respectively in accordance with the American society of testing materials (ASTM). The temperatures were then raised at 10°C per min. and was determined by the means of an optical pyrometer. The maximum temperature available in the furnace was 1300°C and the test cones did not show any sign of failure or deformation, meaning that all the clay samples have a > 1300°C refractoriness.

VI. THERMAL SHOCK RESISTANCE

Test cubes 50mm square were also produced from each clay specimen and put in an electric furnace that already attained a temperature of 900°C. They were soaked there for 20 minutes after which they were brought out and cooled in stream of air. The cubes were tested by using hand to pull them apart. If they do not fracture or crack, they were returned to the furnace for the process to be repeated. This process must continue repeatedly until fracture or crack occurs. The results showed that non of the cubes cracked under 29 cycles.

TABLE 9: MODULUS OF RUPTURE

Clay specimen	**M**	**N**	**O**
M.O.R at 110^oC KN/m^2	6253	6435	6570
M.O.R at 1200^oC MN/m^2	88	89	89

TABLE 10 : THERMAL CONDUCTIVITY

CLAY SPECIMEN	M	N	O
THERMAL CONDUCT W/m^{o}K	0.545	0.489	0.513

VII. RESULTS AND DISCUSSION

Firing Colour Change

The samples showed some darkened colour changes at temperatures of 1200^{o}C from their original colour to ashy black. This was however attributed to the fact that the firewood smoke had serious effect on the colour change.

Sieve Analysis

Tables 1 showed the particle distribution of the clay samples. It was however observed that most of the particles were retained within the sieve mesh of 300µm

CHEMICAL ANALYSIS

TABLE 2 showed the chemical analysis of the clay samples. The results showed that most of the clays were siliceous in nature, having the highest number of silica present. Also the presence of Aluminum oxide of the order of between 25—45% makes them to fall under the class of Alumino-Silicate refractories. Hassan et al (1993)

The high Potassium oxide of samples M, N and O shows that there is high Mica content and this according to Phelps (1958) is good for casting.

Specific Gravity

The specific gravity values of the samples in table 3 fell between 2.5 – 3 and this fell within the ranges for Nigerian clays as reported by Akinbode (1996), Hussaini (1997). It is pertinent to note that the values compared favourably with international range of 2.0 and 2.9. Sample O had the lowest value of 2.58 while sample M had the highest value of 2.69. Obi(1995)

Bulk Density and Solid Density

The bulk densities of the samples were shown in table 4 and the values fell within the internationally accepted range of 1.7—2.1g/cm^3 for fire clays .Thring (1962)

The solid density of the samples also fell within the internationally accepted range of 2.3—3.5g/cm^3. Ryan (1978). The highest solid density value was recorded by sample N while the least was by sample O

Linear Shrinkage

Table 5 showed the linear shrinkage of the samples at 110^{o}C and 1200^{o}C. The linear shrinkage values obtained at 1200^{o}C varied from 9.09 in sample M to 8.17 in sample N. Although this gives an indication of the efficiency of firing, it fell within the internationally accepted value of 7—10% value for Alumino-silicates, Kaolin and fireclays.Zubeiru(1997)

Water Absorption

Table 6 showed the percentage water absorption at 110^{o}C and 1200^{o}C. From the table, sample O showed the highest percentage of water absorbed while sample M showed the least at 110^{o}C. At 1200^{o}C, sample O also showed the highest value while sample N showed the least Hassan (1990).

Apparent Porosity

Table 7 showed the apparent porosity of the samples at 110°C and 1200°C respectively. Sample O had the least value while samples M had the highest at 110°C. Meanwhile all the samples fell within the internationally accepted value of 20% and 80% Thring (1962) for fired bricks. At 1200°C, samples O had the least value of 12% while samples M had the highest of 14%. This shows that as the temperature increases, the percentage apparent porosity decreases, indicating more closure of the pores. This can be increased for insulation purposes by adding saw dust, corn or rice husks. Olusola(1998)

Permeability to Air

The permeability of the samples were presented in table 8. It is important however to state that all the samples had their permeability to air within the internationally accepted value of 25—90, following the observations of Hassan (1990). Sample O recorded the highest permeability to air while sample M recorded the least. High permeability is highly recommended for insulating refractories. The permeability can also be improved by incorporating saw dust and rice husks in the clay, while molding. Manukaji(2004)

Refractoriness

For the fact that all the samples did not show any sign of failure at temperatures of 1200°C and above, it means that their sintering level is very high and will fall within the internationally accepted range of 1580°C – 1750°C. This eventually showed that the samples have high and good refractoriness qualities and can withstand the high temperatures the clay will be subjected to in operation. Abifarin(1999)

Thermal Shock Resistance

All the samples showed a thermal shock resistance of 29+ cycle. The thermal shock resistance values for the samples are acceptable for siliceous fire clays. This property is vital for materials used in places where heating and cooling operation is carried out repetitively Agha(1998).

Modulus of Rupture

Table 9 showed the values of modulus of rupture for all the samples. At 110°C sample M showed the least value while sample O showed the highest value. At 1200°C, all the samples showed an improvement in their modulus of rupture but sample M still recorded the least while sample N and O recorded the highest values Ijagbemi (2002).

Thermal Conductivity

Table 10 showed the values of the thermal conductivity test for all the samples. The values showed that specimen N had the least thermal conductivity value, while the highest value was specimen M. Ijagbemi(2002)

VIII. CONCLUSION

With a critical look on the properties of the clay samples surveyed, tested and analysed during this investigation, the following conclusions can be deduced.

(1) From the chemical analysis, all the clay samples had silica and alumina as the predominant substances and it could be concluded that they are siliceous in nature and are of the Alumino-Silicate refractories.
(2) The water content of the clay samples made handling of the clay (mouldability) very possible. The fire shrinkage values which hovered between 8 and 10% were found to be within the internationally accepted range for clays. The clays from sites showed a permeability range of 68-82% which also falls within the range of 24-92% for typical fire clays bricks. The apparent porosity of the clays, compared favourably with the normal acceptable standards as they fell between 20 to 25%. The samples had a thermal shock range of 29 cycles, which closely coincided with the acceptable values internationally. The internationally acceptable range for bulk density is between 1.7 to 2.2 g/cm ^{3} and the samples fell within the range thereby conforming to the approved values. The refractoriness of the clays showed that the clays could withstand temperatures between 1200 to 1600°C which is good for industrial use.

Recommendations For Further Work

With the studies carried out, and the analysis done of the accruing results, the following recommendation for further studies and analysis is hereby proposed.

(1) Further studies on the insulating properties of the clay samples could be carried out by analyzing the effects of the addition of rice husks, ash and other farm wastes on the clay samples.
(2) An investigation should also be carried out on the effects of the addition of bentonite on the clay samples.
(3) A study should also be carried out on how the addition of graphite, coal and asbestors would reduce the linear shrinkage properties of the moulded base plates.

(4) Efforts should also be made to reduce the ferrous and ferric content of the samples thereby reducing their thermal conductivity.
(5) Slag from iron extraction should be added to the samples to improve their insulating properties.
(6) Investigation should be made on the effects of the addition of foam-ceramic-fibres on the insulating properties of the samples.

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