Triaxial Testing of Okpella Granite with Kaolinite Material to Achieve Workable Ceramic Refractory

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ABSTRACT

The use of locally sourced materials towards meeting our local needs is inevitable in this era of recession, especially in Nigeria. There is the urgent need to discourage the extreme and awkward dependence of local potters and ceramists on imported materials and ceramic items so as to profound substitute-able solutions to the challenges facing the country's ceramic production. Local alternative to the sustenance and survival of the ceramic industry is paramount especially to the developmental and technological growth of our economy. It is this quest that necessitated the need for a research development and documentation of locally sourced refractory materials using three materials namely Granite, Ball Clay and Kaolin. These were compounded to derive working formula for a workable refractory in ceramic production, after a series of tests on different formulae. The result analyses from the Centre for Energy Research and Training, (CERT) Ahmadu Bello University, Zaria in Nigeria shows a relatively high percentage of refractoriness as found in Silicon Dioxide which in Granite was 50.7 percent, Ball Clay 61.2 percent and Kaolin 42.4 percent.

INTRODUCTION

One of the properties often looked out for in the production of any refractory material is its ability to withstand high melting temperatures without deformation. They are predominantly ceramic materials employed in great quantities in the metallurgical, glass making, and ceramic industries. Refractory property must be present in the materials to be used, especially in clay which must have the ability to withstand high temperature. The use of Granite as filler in the granitoid body formulation facilitates the production of the desired refractory with such qualities of exceedingly hard physical strength, high thermal conductivity and ability to withstand high temperature strength. The combination of Okpella granite with Auchi Kaolin and Ball clay in the production of granitoid refractory body formation will go a long way at addressing some needs in ceramic items as Kiln Bricks, Kiln Bats, Props, Collars and Stilts.

Today, it would be difficult to imagine the consequences of a world without ceramics, a world without bricks, tiles, pottery and especially ceramic refractories. The utilization of these natural resources would go a long way at meeting some of our needs as noted by the former United States President Bill Clinton and buttressed by Ayittey, (2011: 1) that "The solution to Africa's problems lies within", there is therefore the need for us to look inward especially at coherent ideas of studying granite in combination with other materials for the production of required ceramic refractories needed in kiln walls, bricks, bats and props.

Refractories

Any material with the ability to retain its enactness at any given temperature is known to be refractory. Such could be interpreted as the reduction in body fusion. Besides being formed into a variety of shapes, they line the interior of furnaces, kilns, and other devices of high temperature. However, refractories are of significant importance which make for technological advances, influenced by the availability of better refractories made of clay materials. (Kassim, 2003). Oyeoku states that "the physical properties of good clay must be considered when deciding on the type of clay to use, this of cause are considerations to be looked into." (Oyeoku, 2006: 46)

Similarly, refractory materials will not deform or get damaged at high temperatures because the refractory residual or primary clays which withstand a very high degree of heat without melting are present in them. (Sanders 1971: 19). Thomas (2014: 1) describes refractory as any material that has an unusually high melting point, and that maintains its structural properties at very high temperature. It will be added that this material may be chemically an acid, basic, or neutral, dependant on the application. Silica (made from sand or quartzite), zircon (from extreme heat resistance), and fire clay (made by baking kaolin) are acid; magnesite and dolomite are alkaline; high-alumina refractories, mullite, chromite, silicon carbide, and carbon are neutral. The mineral granite, belong to the silicate group and are known to be resistant to high heat.

Properties of Refractories

Most ceramic materials possess the characteristics of a refractory and because of the high strengths exhibited by the primary chemical bonds, many of them have unusually good combinations of high melting point and chemical inertness. This makes them useful as refractories. In the similar echelon, Opoku, (2006: 2) opines that refractory ceramics and enabling materials for other industries, all rely on refractory materials. This property of chemical inertness is of special importance in metallurgy and glass making. It is also important in furnaces exposed to extremely corrosive molten materials and gases. In addition to temperature and corrosion resistance, most refractories possess superior physical wear or abrasion resistance, and resistant to thermal shock. Thermal shock occurs when an object is rapidly cooled from high temperature.

Ceramic refractories in spite of their well-known brittleness or thermal strength can be made resistant to thermal shock by adjusting their microstructure during processing. The microstructure of ceramic refractories is observed to be quite coarse when compared with white-wares such as porcelain or even with less finely textured structural clay products such as brick. On the other hand, Alasa, (2005: 8) explains that primary clay has high fire strength and low fire shrinkage. It has high resistance to excessive temperature such that it can withstand a temperature of above 1750^oC. He states further that this primary clay abounds everywhere in Nigeria, especially at Igara in Akoko-Edo Local Government Area and Auchi in Etsako West Local Government Area of Edo State. Also, the findings of Osariyekemwen (2015), Kalilu and Emeriewen (2011:11) as well as those of Ohimai et al (2011:11) confirmed that porcelain waste like broken china ware, discarded water closets and tiles which have granite as silica raw material were recycled through pulverization and refractory heat treatment provided to be suitable for Production of ceramic refractory products and also suitable for polishing and buffing.

Granite

As a result of its use as concrete block and as building stone, the quarrying of granite was, at one time, a major industrial activity. Except for tombstones for which there is a long-lasting demand, the present production of granite is geared to the unpredictable market for curbing in highway construction and veneer used in the facing of large industrial and commercial buildings. Both plagioclase feldspar and alkali feldspar are usually abundant in it, and their relative abundance has provided the basis for granite classifications. Taking a look at the Mohs' Scale of Mineral Hardness, Granite is surpassed only by Corundum, Topaz and Diamond. (Samsonov, 2013:4) In most granite, the ratio of the overriding to the subdominant feldspar is less than two. Granites with a huge excess of alkali feldspar over plagioclase are known to development in northern Nigeria. In most granite, the ratio of the overriding to the subdominant feldspar is less than two. Granites with a huge excess of alkali feldspar over plagioclase are known to development in northern Nigeria.

Rocks containing less than 20 percent quartz are almost never named granite, and rocks containing more than 20 percent (by volume) of dark, or ferromagnesian, minerals are also seldom called granite. The average chemical composition of granite according to Harvey and Robert, (1997: 66) is as follows:

SiO_2 – Silicon dioxide – silica — 72.04%

Al_2O_3 - Aluminum oxide – alumina — 14.42%

K_2O - Potassium oxide — 4.12%

Na_2O - Sodium oxide — 3.69%

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CaO - Calcium oxide — 1.82%

FeO - Iron (II) oxide — 1.68%

Fe_2O_3 - Iron (III) oxide — 1.22%

MgO - Magnesium oxide — 0.71%

TiO_2 - Titanium dioxide — 0.30%

P_2O_5 - Phosphorus pentoxide — 0.12%

MnO - Manganese (II) oxide — 0.05%

Sourcing and Processing of the Raw Materials

All the raw materials required for executing this refractory were sourced from Edo State. It is one of the many states in Nigeria with vast prospect of reserves in varieties of useful minerals except that most of them are yet to be exploited. As expressed in the website of the Nigerian Embassy in Korea, statistically, the level of exploitation of these minerals is very low in relation to the extent of deposits found in the country (Akawor 2013: 1).

Ball Clay and Kaolin of high refractory characteristic were obtained from Auchi in combination with the main mineral granite, fetched from Okpella which is about twenty-five kilometre drive from Auchi in Edo State of Nigeria. Okpella is a tranquil community on the crest of immersed mountains of Granite along Benin – Abuja express road that is positioned in the north western part of Etsako East Local Government Area of Edo State.

The materials were compounded to derive a working formula for a workable crucible in ceramic production after a series of tests on different formulae. The different recipes were also subjected to both physical and laboratory test in order to obtain qualitative and possibly quantitative data on the required granitoid composite hence, the method so adopted in the study was exploratory and experimental.

Diagram 1: Map of Edo State of Nigeria showing Auchi and Obviomu location

Courtesy: Encarta, Microsoft Corporation

The raw materials used for the production of the test tiles are:

1. Granite
2. Kaolin
3. Ball clay

Locating the Raw Granite Material

Granite, the main mineral granite was fetched from Okpella which is about twenty five kilometer drive from Auchi in Edo State of Nigeria. Okpella, is a tranquil community on the crest of immersed mountains of Granite along Benin – Abuja express road that is positioned in the north western part of Etsako East Local Government Area of Edo State.

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Figure 1: Mountain of Granite Rock at the Quarry Site at Okpella

A lot of the granite rocks quarrying activities are ongoing at Okpella and as such, it was not difficult getting the materials crushed and milled. The crushing of granite rock is a major business Okpella people pride themselves with. A first time visitor to the community is confronted with a sculptural edifice depicting this activity. (See figure 2).

Figure 2: A mounted Sculptural piece in Okpella depicting granite crushing activity in the locality

Apart from the mechanized method of crushing granite the local people who are mostly women are involved in the manual commercial crushing using strong metal against the rocky material. It was observed too, that the local women built shields near the mountains of granite rocks. This is where with the assistance of their children, they manually quarry the rocks using hard metal consisting mostly of old automobile parts in the crushing the rocks for commercial gain.

These women most times sit on their heels under the erected shield breaking these large pieces of rocks into smaller pieces for sale. They are used for building and road constructions, with regular risk of hand and eye injuries. Collaborating this assertion and expressing concern over the women in Mokwete, South Africa who takes to stone breaking as jobs, Mazibuko (2013: np) explained that it is surely one of the worst jobs in Africa seeing how these women squat in the hot sun and hammering away and smashing large rocks into small ones, stating also that stone breakers expend joint-straining amounts of muscle power, face a constant risk of hand and eye injuries, and breathe in huge quantities of harsh stone dust.

Kaolin

Deposits of kaolin as expressed by Nordgren, (2014: 26) are sedimentary materials and composition depending directly on where they are formed. Such kaolin deposits are abundant in Nigeria. According to Durojaiye, (2005: 10)

> *The Federal Government of Nigeria has identified 111.66 million tons of kaolin in 12 states of the federation with the largest deposits of 40 million tons located in Owo Local Government Area of Ondo state. Kaolin deposits in other areas include 12.8 million tons in Darazo Local Government Area of Bauchi state, 12.6 million tons in Agbaja area of Kogi State, 7.5 million tons of kaolin deposit are in Isan*

and 6.4 million tons in Ijero areas of Ekiti State. In Kebbi state are 6.8 million tons of kaolin deposits identified in Argungu Local Government Area. There are 6.86 million tons in Awomamma area of Imo state, while Abeokuta North Local Government Area of Ogun State has 2.8 million, 2.1 million tons in Barkin Ladi Local Government Area of Plateau State, 7.5 million tons in Itu Local Government Area of Akwa Ibom, 2.5 million tons in Ozubulu area of Anambra state while Buan area in River State has 40,000 tons.

The earth materials are abundant in nature and with reference to Nigeria; good workable clay are not difficult to locate even in most towns that were not originally noted for pottery making (Okpalla, 2012). Nigeria has about 800 million tons of quantifiable proven deposits of kaolin, these deposits of kaolin are visually in all parts of Edo State but such deposits are yet to be quantified or exploited. Source: Raw Mineral Research Development Council (2015)

This is the soft white clay usually of low plasticity, low shrinkage and high fire resistance. Apart from being a refractory material at a high temperature, it serves as a binder for this research work. It helps to unite other raw materials used in the composition. Huge deposits of this mineral abound in and around Auchi terrain. This location consists of heaps of layers of kaolin that are available for exploitation. The researcher personally took a trip to kilometer four along Auchi – Igarra road where 150 kilogram samples of kaolin were excavated using digger and shovel. The non-kaolin top soil was carefully removed to avoid contaminating the real kaolin. Subsequently, the lumps of kaolin were spread out to dry, crushed using wooden mortal before screening in a hundred mesh sieve to get the fine particle grain size. The use of Kaolin in this research work was necessitated not just for its refractoriness, or its characteristic of brittleness which is the degree to which the material can easily break, but because it remains the purest form of all clay and it serves as binder for all materials used. (Otimeyin, 2021)

Figure 3: The kaolin deposit along Igarra Road, Auchi

Ball Clay

Ball clay is a secondary type of clay known for its natural dark greyish colour and high plastic characteristics. When compared to kaolin, it is less refractory but when fired it turns whitish or cream in colour. The secondary ball clay formation according to Kashim, (2001:60) can be found everywhere in Nigeria while Ibude, (2012: 95) on studying the deposits at Auchi-Igarra road explains that the exposed ball clay was made known as a result of the road construction and its dark colour has been traced to the presence of carbonaceous materials. They have a geological origin from the primary clay (kaolin) and they are characterized by fine particles sizes, plastic but contain some iron impurities. Though ball clay are commonly high in carbon, organic content and impurities, they are desired to give the needed plasticity needed during the forming of the body.

Ball clay in the words of Olawepo, (2010:10) is said to be high in iron content, fusible, plastic, fine in particles and impact a great dry strength when used as a body component. This assertion may be partially correct because should the ball clay contain high iron content, it ought to turn red when fired. It is said that they are fine particle size kaolinitic clays that are plastic and range from light gray to nearly black naturally. The dark colour is due to the presence of organic matter in the form of lignite or peat. (Haydn, 2000:21) Deposits of this ball clay were

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also found side by side kaolin along Auchi – Igarra road. There, a 100-kilogram sample was dung and collected for this research work using shovel and digger.

Procedure for Test Analysis of Samples

The necessary steps adopted in carrying out this research involved both the direct field examination of the materials and laboratory analysis of the different specimen. The different recipes were also subjected to both physical and laboratory test in order to obtain qualitative and possibly quantitative data on the required granitoid composite hence, the method so adopted in the study was exploratory and experimental. The sample materials were taken to the laboratory for the breakdown of the chemical analysis. The Mini Pal equipment which is a compact Energy dispersive X-ray spectrometer designed for the elemental analysis of a wide range of samples was used. The sample for analysis was weighed and grounded in an agate mortar and a binder (PVC dissolved in Toluene) was added to each sample. Therefore, they were carefully mixed and pressed in a hydraulic press into a pellet.

Figure 4: The Mini pal 4 Spectrometer with Displayed Pellets

Each of the pellets was loaded and placed in the sample chamber of the spectrometer with a maximum voltage of 30KV and a maximum current of 1mA was applied to produce the X- rays to excite the sample for a preset time of 10mins in this case. The spectrums from each sample were then analyzed to determine the concentration of the elements in the sample. This test was conducted at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, Nigeria

Table1: Chemical Analysis of Granite Sample from Okpella Area

Application	<Standardless>
Sequence	1 of 1
Measurement date and time	12-Mar-2013 14:15:03
Position	3

Compound Name	Compound Formula	conc. Unit
Aluminum (lll) Oxide	Al2O3	12.1
Silicon Dioxide	SiO2	50.7
Phosphorus Pentoxide	P2O5	0.46

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Potassium Oxide	K2O	8.25
Calcium Oxide	CaO	5.52
Titanium Dioxide	TiO2	0.858
Chromium (lll) Oxide	Cr2O3	0.064
Manganese (ll) Oxide	MnO	0.14
Iron oxide	Fe2O3	8.508
Nickel (ll) Oxide	NiO	0.056
Copper (ll) Oxide	CuO	0.11
Zinc Oxide	ZnO	0.048
Gallium (lll) Oxide	Ga2O3	0.023
Rubidium Oxide	Rb2O	12.0
Rhodium (lll) Oxide	Rh2O3	0.18
Barium Oxide	BaO	1.11
Osmium Tetroxide	OsO4	0.11
		100.237

Table2: Chemical Analysis of Kaolin Sample from Auchi Area

Application	<Standardless>
Sequence	1 of 1
Measurement date and time	12-Mar-2013 14:02:55
Position	1

Compound Name	**Compound Formula**	**Conc. Unit**
Aluminum (lll) Oxide	Al2O3	21.8
Silicon Dioxide	SiO2	42.4
Phosphorus Pentoxide	P2O5	0.50
Calcium Oxide	CaO	0.11
Titanium Dioxide	TiO2	11.40
Vanadium (V) oxide	V2O5	0.43
Chromium (lll) Oxide	Cr2O3	0.11
Iron oxide	Fe2O3	2.16
Nickel (ll) Oxide	NiO	0.15
Copper (ll) Oxide	CuO	0.096
Gallium (lll) Oxide	Ga2O3	0.03
Rubidium Oxide	Rb2O	17.00
Rhodium (lll) Oxide	Rh2O3	1.60
Cadmium Oxide	CdO	2.30

Osmium Tetroxide	OsO4	0.17
Iridium Oxide	IrO2	0.23
		100.486

Table3: Chemical Analysis of Ball Clay Sample from Auchi Area

Application	<Standardless>
Sequence	1 of 1
Measurement date and time	12-Mar-2013 14:08:50
Position	2

Compound Name	Compound Formula	Conc. Unit
Aluminum (lll) Oxide	Al2O3	19.6
Silicon Dioxide	SiO2	61.2
Potassium Oxide	K2O	1.91
Calcium Oxide	CaO	0.48
Scandium Oxide	Sc2O3	0.03
Titanium Dioxide	TiO2	3.45
Vanadium (V) oxide	V2O5	0.19
Chromium (lll) Oxide	Cr2O3	0.10
Manganese (ll) Oxide	MnO	0.003
Iron (lll) Oxide	Fe2O3	11.40
Nickel (ll) Oxide	NiO	0.12
Copper (ll) Oxide	CuO	0.070
Zinc Oxide	ZnO	0.03
Gallium (lll) Oxide	Ga2O3	0.041
Zirconium Dioxide	ZrO2	0.2
Rhodium (lll) Oxide	Rh2O3	1.0
Rhenium (Vll) Oxide	Re2O7	0.10
		99.924

The Granite, Kaolin and Ball Clay samples were analyzed using energy dispersive X-ray fluorescence technique. The mini pal 4 PW 4030 x-ray spectrometer determined the elements that are present in each material and the rate at which such elements were present. The X-ray fluorescence (XRF) is the instrument used to analyze the chemical of the rock minerals using the interaction of X-rays to determine their elemental composition. It is the most widely used method of analyzing major and trace mineral elements in rocks made possible by the interaction atoms with radiation, working on wavelength dispersive spectroscope principles.

Taking a close look at the compound elements that are present in the three samples analyzed, it was observed that a total of twenty-three different elements were involved and efforts were made to find out the melting points

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of each of these elements as captured in the table below;

Melting Points of the Different Elements

Table 4: Chemical Name and Formula Showing the Melting Point

S/N	Compound Name	Compound Formula	Melting Point
1	Aluminum (lll) Oxide	Al2O3	2,072 °C
2	Barium Oxide	BaO	1,923 °C
3	Cadmium Oxide	CdO	900 - 1,000 °C
4	Calcium Oxide	CaO	2613 °C
5	Chromium (lll) Oxide	Cr_2O_3	2435 °C
6	Copper (ll) Oxide	CuO	1,201 °C
7	Gallium (lll) Oxide	Ga2O3	1,900 °C
8	Iridium Oxide	IrO2	1,100 °C
9	Iron (lll) Oxide	Fe2O3	1,566 °C
10	Manganese (ll) Oxide	MnO	1,945 °C
11	Nickel (ll) Oxide	NiO	1955 °C
12	Osmium Tetroxide	OsO4	40.25 °C
13	Phosphorus Pentoxide	P2O5	340 °C
14	Potassium Oxide	K2O	>350 °C
15	Rhenium (Vll) Oxide	Re_2O_7	360 °C
16	Rhodium (lll) Oxide	Rh2O3	1,100 °C
17	Rubidium Oxide	Rb2O	>500 °C
18	Scandium Oxide	Sc2O3	2,485 °C
19	Silicon Dioxide	SiO2	1600-1725 °C
20	Titanium Dioxide	TiO2	1,843 °C
21	Vanadium (V) oxide	V2O5	690 °C
22	Zinc Oxide	ZnO	1,975 °C
23	Zirconium Dioxide	ZrO2	2,715 °C

Elaborating on the Tri-axial Blend

Shown fully on the points of the triangle blend consisting of 66 positions of different compositions, beginning with the top point (position1) the composition with 100% Granite material G. The left point (position 56) consist of composition with 100% Kaolin material tagged K, while the right point (position 66) has the composition with 100% Ball Clay material labeled B. The positions between I and 56 on the left point composition are combining material G and K, the base point in between compositions 56 and 66 are combining material K and B, while positions between 66 and 1 on the right point are composition combining material B and G all other points in the middle of the triangle are a combination of the three materials.

A careful study of the tri-axial blend shows a horizontal base of boxes 56-66 capturing only Kaolin and Ball Clay and since the research work focuses on Granitoid material, such absence of the material Granite ought to nullity composites 56-66, however, the test was carried out to enable further observation of the blend.

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Shrinkage Test

The dry shrinkage test enables the determination of the strength of each sample because shrinkage is invariably related to the dry strength of any ceramic ware. This is simply the test result of the reduction in size of any ceramic material due to drying or firing. Linear shrinkage is calculated by first measuring out the compounded body sample, mixed with the desired water ratio and formed to shape. After the body samples where formed to shape, the dimension at the green state was carefully measured and recorded as LI, then after firing, the fired dimension was also measured and recorded as L2. The linear shrinkage was approximated according to the relation. A 10 cm length mark was impressed on each of the slab surface, they were then left to dry for a week, thereafter, the Dry Length was measured by using ruler to read the two edges of mark drawn on the dried clay slab before converting to millimeter, the dry shrinkage was subsequently calculated using the converted drawn line which was 10 centimeter to 100 millimeter minus the dry length in mm to indicate the result change per cent in length between the wet and dry slab.

Loss of Ignition Test

This percent loss in the weight of the fired slab is what is referred to as the Loss of Ignition (LOI) was carried out by first weighing the dry slabs and thereafter fired to a very high temperature of 1180 °C before weighing again. It would be observed that the loss in weight was due to the burning off of organic matters in the clay body, water of crystallization and the liberation of different gases by chemical processes that took place while firing the test slabs. The Loss of Ignition (LOI) test gives an indication to the rate of body porosity and strength.

Discussion of Findings and Observations from Studio Test Carried Out

The diverse findings and observations were resultant of the field work; studio experimentation and tri-axial test sample consisting of Granite, kaolin and ball clay are of Sixty Six (66) test sample composite of different percentages from three different materials arranged in a triangle formed into clay body slabs or tiles to show the effect of such combination in the tri-axial blends. In determining if the result analyses from the composite are suitable for determining efficiency and refractoriness the compounded formulae of the test samples was analyzed, the findings, the result analyses of the three materials of Granite, Ball Clay and Kaolin.

Since the melting temperature of the element Aluminum (Ill) is 2,072 °C and Silicon Dioxide 1600 - 1725 °C they were, at the compounded percentages able to give enough refractoriness in a ceramic body. Apart from the test samples 1, 2, 3 and 4 in tri-axial blend that fused under 1180°C, all other test samples were able to stand the high temperature without warping or deforming.

Modulus of Rupture Test

Modulus of rupture which could be called bending strength or tensile strength is a property that is very important in ceramic manufacturing industries because a well vitrified ceramics tends to have high strength and well reduced breakages during handling and when put in use. The use of compressive test machine at the Civil Engineering Department in Auchi Polytechnic, Auchi proved abortive, as the machine was designed for larger samples and as such the compressive impact reading became impossible. However, the use of an alternative to carry out the tensile strength test (modulus of Rupture) on smaller item was used.

Apparatus:

(1) Locally fabricated modulus of Rupture machine

(2) Loads of rapture

(3) Supports

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Figure 5: Locally fabricated Modulus of Rupture Machine

Note any suitable method can be used, provided a uniform rate of direct loading can be maintained using the prescribed specimen. More so a regular weight increase/unit of the sample must be guaranteed.

Test specimens (A –J) 10 samples from the most appropriate of Tri-axial, Shrinkage and Loss of Ignition Tests were controlled

Procedure: The samples A – J Specimens were placed on the two of the MOR edges with the specimen overlapping each end by a least 1cm. The load was therefore applied at the right angles on top of the loads support pan of the machine which has a midi-ray pencil like rod between the supporting edges. The loads were applied uniformly at the approximate rate of 1020kg/cm to 20kg/cm per second until breakage occurred. The modulus of Rupture of A - J Specimens were calculated from the following formula

Modulus = $\frac{3PL}{2ab2}$

Where P = Load of Rupture

L = distance between supports

A = Width of specimen

B = Thickness of specimen

3 and 2 are constant

Source: Introduction to Industrial Ceramics by S.J.E Igbinedion 1995, Page 13

Note: The tensile strength test conducted on samples show that samples I and J respectively are best suitable samples for normal refractory production. See summary result below.

Summary results of the tensile strength test conducted on samples

Table 5: Shows the result of the Tensile Strength (MOR) test

MOR Specimens	Breaking Load Applied Kg	Caclulated Results Kg/Cm2
A	14.9 kg	19.9 kg/cm2
B	15.6kg	20.5 kg/cm2
C	16.2 kg	21.6 kg/cm2
D	16.5 kg	22.1 kg/cm2
E	16.8 kg	25.4 kg/cm2
F	16.8 kg	25.5 kg/cm2
G	16.9 kg	30.1 kg/cm2

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H	16.9 kg	30.4 kg/cm2
I	17.1 kg	30.8 kg/cm2
J	17.3 kg	31.5 kg/cm2

CONCLUSION

It was true that the most important property of any ceramic material is its refractoriness. This invariably determines the ability of the refractory to withstand high temperature; it shows clearly that superior refractory materials which could withstand higher temperature up to 1500ºC are in existence today. More ceramic refractory materials are still being discovered and refined due to improved technology. There is for example a wide range of alumino-silicate materials being integrated into modern ceramic refractory productions. In order to modify product refractoriness, there exists a high mechanization of materials which initially consisted highly of heterogeneous composite but are refined into a more homogenous body with a lot of test equipment available to cheek both the chemical and mechanical properties especially the properties of refractory such as the thickness, the particle size distribution and so on.

Granite, Kaolin and Ball Clay are all refractory materials that would not deform at temperatures below 1250ºC but are both plastic and non-plastic combination which when modelled into refractory are sufficiently refractory to withstand high temperature. The granite was of high quality, the kaolin was soft and of less impurity while the ball clay mainly found in strata were of the required plasticity needed for the binding together of the non-plastic materials It has been observed that the most appropriate ratio of all the composite test pieces suitable for the production of ceramic refractory in this research work was sample 18 in tri-axial blend 'A' with Granite at 50%, Kaolin at 30% and Ball Clay at 20% having a shrinkage of 7.5%, water absorption of 3.8%, and modulus of rupture put at 17.3 kilogram. The high percentage of refractoriness as found in Silicon Dioxide which in Granite was 50.7, Ball Clay 61.2 and Kaolin 42.4 is a proof of high refractoriness.

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