AFRREV IJAH
An International Journal of Arts and Humanities
Bahir Dar, Ethiopia
Vol. 3 (2), S/No 10, April, 2014:179-197
ISSN: 2225-8590 (Print) ISSN 2227-5452 (Online)
Doi: http://dx.doi.org/10.4314/ijah.v3i2.11

Developing a Refractory Body for Kiln Building in Nigeria

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Abstract

Pottery today is the outcome of centuries of growth and its beginning in Nigeria stretches back into pre-historic times, a period without written history but potters have since learned much. Any potter who intends to make a living from this craft needs a kiln which combines reliability with economy. In the past thirty years, potters and entrepreneurs in Nigeria have set up many pottery studios. A good number of these pottery studios have not survived partly due to difficulties in procuring a functional kiln and sourcing for cheap and readily available fuels for firing. Firing is considered a crucial stage and the turning point in the process of pottery making. The researcher therefore considers it a challenge to develop a refractory body suitable for the construction of kerosene kiln. This research therefore intends to encourage potters to change their method and material

utilization habit through local sourcing and experimentation with some of the locally available resources at hand.

Introduction

Ceramics has an extremely long and varied history. Archaeological discovery of fragments from clay vessels of prehistoric human activities across Eurasia about 70,000BC to 35,000BC proved that those people had knowledge of fire. They lined their twig basket with clay to make them hold water or food and one day those vessels were accidentally put on fire, leaving a hardened clay vessel. (Peterson 1992). Consequently, it becomes apparent that the process of firing clay to make it hard and durable is an age long tradition.

The history of the kiln is actually the evolution over a long period of time from the simple shallow pits into a fixed structure designed to direct and contain the heat of the fire. Kiln actually is not an invention but rather the outcome of a series of small improvements from open firing to the development of Electric Kilns, and this happened some 80 years ago. Before the development of the electric kiln, pots were fired in different flame burning kilns using fossil fuels like coal, wood oil, kerosene or gas. Electric kilns offer the straight test forward and trouble free method with obvious advantages over the other fuel burning kilns. They are portable, relatively light and compact; it requires no chimney and can be operated without special skill or knowledge. One needs only to turn on the switches and turn them off when the desired temperature is attained. If fires uniformly with little variation in result.

With such an impressive list of advantages one might ask, why have these electric kilns not flooded our schools, pottery centers studios and industries? Or why has it not supplanted all other types? The answer is that electric kiln costs three times as much for a large gas, kerosene or oil kiln. Then is the cost of electric power which is very high in developing countries. For example, Nigeria has the problem of power failures, power fluctuations and no power at all. The other more serious disadvantage is the size limitation. Rhodes (1981) notes that

Electric kilns do not perform too well if the inside measurement exceeds 2½ feet across. This size limitation does not permit the firing of large pieces. Other necessary accessories like elements, pyrometers and switches among others, are costly and not readily available in Nigeria. Another fault is the life expectancy of electric kiln, good elements last only for a period of five years without accident. The greatest wear occurs if the kiln is used for reduction firing. Electric kiln is selective in the type of ceramics which can be fired in it because of the unchanging nature of the chamber.

Wood, charcoal, coal, diesel kerosene and oil are other sources of heat. Wood and charcoal are the ancient traditional materials for firing pottery and are still used extensively in areas where wood is available. Its kiln needs large space and because it creates a lot of smoke it has to be located in relatively isolated areas.

Coal can be used to replace wood. It is a combustible rock which has its origin in the accumulation and partial decomposition of vegetation. (Adams 1955). Nigeria is blessed with this cheap source of fuel but management problem has very much affected the industry and supply of it. Wood and coal kilns are specially designed to fire heavy industrial products.

Gas is the ideal fuel for kilns. The flow to its burners is continuous and easily controlled. It is noted for its cleanliness and its kiln is easy to build. Nigeria is endowed with this mineral but to construct a gas kiln in this country is highly uneconomical. Oil is an excellent fuel for kilns. Baily, Battershill and Bressey (1946) classified it as the oils that together with bitumen, make up the residue after crude oil has been distilled to give off petrol, paraffin, oil, gas, diesel and motor oil, but the price of oil, which used to be comparably cheap, has gone up in this country, making its use less economical for the ceramist. The problem with oil is to break it down into fine droplets or mist, so that air can mix with it for rapid combustion. The most efficient burners using pressure and heat can reduce oil to a vapour, which burns in a manner similar to gas.

Sourcing of Materials and Method of Production

The researcher carried out various field surveys in locating and sourcing for materials to be used. The location, description, structure and analysis of collected samples were carried out. The requirement of ceramic bricks for kiln building generally involve knowledge about the following properties: refractoriness; the ability of that materials to behave as an insulant; resistance to thermal shock; abrasion and impingement resistance; resistance to slag, fumes etc; and good constructional properties.

The need for understanding the sources and properties of the materials is very important. The exact choice of refractories for constructing ceramic kiln will depend primarily on the maximum temperature to which the ware is to be fired. The researcher is planning to produce bricks that will withstand a temperature up to 1250^{0}C range. Materials high in aluminosilicate, silica and magnesite etc will be sourced. Test of the refractory materials will be carried out.

Investigations already carried out reveal that the following areas have good materials for such refractory and insulating bricks.

Material	Local/Source	State
Ukpor (Kaolin)	Ozubulu	Anambra
Nsu (Kaolin)	Osu Mbano	Imo
Ugwuogba (Kaolin)	Nsukka	Enugu
Bata River (Kaolin)	Benin	Edo
Fire clay	Coal mine Enugu	Enugu
Silica	Nsude	Enugu
Umuchu clay	Umuchu	Anambra
Nafula (Kaolin)	Jos	Plateau
Kaukare	Jos	Plateau
Uturu clay	Okigwe	Imo
Nnewi clay	Ihiala	Anambra
Okija clay	Ihiala	Anambra
Silica	Abeokuta	Ogun

Source: Raw material and Research centre Federal Secretariat Enugu.

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The list of sources of refractory materials is very extensive but one might ask, what distinguishes a refractory from other materials? Substances with melting points or fusing temperatures above 1580^0C are termed refractories while others with lower fusing points are sometimes processed to remove fluxing impurities thereby making them meet up with the refractories.

According to Shaw (1972), a material can be described as 'refractory' if it can stand up to the action of corrosive solids, liquids, or gases at high temperatures. The various combinations of conditions in which refractories are used, make it necessary to manufacture a range of materials with different properties. This involves selecting raw materials with specific characteristics processing them and finally fabricating them into shapes with the desired combinations of properties to meet the particular demands of a given work condition.

The classification of the raw material proposed for use in the production of the bricks has already been carried out and are as stated in tables 1, 2, 3 and 4.

Table 1: Enugu Fireclay

Analysis of sample (dried at 110^0C)

1	Silica (SIO_2)	% 71.86
2	Titanic oxide (TIO_2)	2.15
3	Alumina (Al_2 O_3)	14.32
4	Ferric oxide (Fe_2O_3)	3.13
5	Magnesia (Mg0)	0.15
6	Lime (C_a0)	0.08
7	Potash (K_20)	0.45
8	Soda (Na_20)	0.08
9	Loss (calcined at 950_00)	7.37

Calculated proximate (rational) analysis

1	Clay	% 35.4
2	Feldspar or Mica calculated as feldspar	3.3
3	Quartz	55.6
4	Lime compounds calculated as C_a0	0.1
5	Titanic oxide	2.2
6	Magnesium compounds (Mg0)	0.2
7	Ferric oxide	3.2

Source: Nigerian coal corporation information manual

Materials

Table II: Chemical analysis of materials

Materials	LOI	$S_1,0_2$	Al_20_3	Fe_20_3	$T10_2$	C_a0	Mgo	Na_20	K_20	Mno	P_205
Feldspars	0.45	6577	18.11	0.28	-	0.17	0.02	8.05	1000	-	-
Silica	0.612	99.158	0.737	0.055	-	-	-	-	-	-	-
Ukpor kaolin	12.04	51.43	31.34	1.63	2.43	0.06	0.06	0.04	0.10	-	-
Nsu Kaolin	9.14	60.15	25.78	2.16	1.70	0.12	0.12	0.03	0.17	-	-
Jos Kaolin	13.76	43.74	28.10	1.77	1.98	0.11	0.11	0.02	-	-	-
Whiting (lime)		0.03	00.97	0.043	-	55.78	55.78	-	-	0.006	0.001

Physical analysis of some refractory clay

Table III

Materials	% drying shrinkage	% making moisture	Green strength kgf/cm^2	Plasticity ratio	Firing tempt	% friend shrinkage	% total shrinkage	Fried strength	% App porosity	% water absorption
Ukpor clay	7.40	25.50	16.50	5.9.1	1050 1100 1150 1200	3.50 3.70 9.90 12 70	10.60 1080 16.60 19.20	45.40 46.50 75.50 76.60	38.80 37.70 27.30 20.30	22.30 22.0 13.90 9.80
Nsu clay	5.80	27.10	10.98	5.1	1050 1100 1150 1200	2.97 3.60 8.07 9.60	8.60 9.20 13.40 14.80	214.90 223.70 251.80 314.30	39.50 38.30 33.20 25.20	23.50 21.70 16.30 11.20
Fire clay Enugu	8.60	20.80	29.70	2.8.1	1050 1100 1150 1300	0.44 0.66 1.97 2.20	9.00 9.20 10.40 1060	156.10 162.80 235.60 346.70	29.40 28.80 27.40 25.30	14.60 13.90 13.60 11.90

Table IV: Chemical analysis of independence (new haven)

Brick clay

1	Silica (S_1O_2)	57.32
2	Titanic oxide (T_1O_2)	0.33
3	Ferric oxide (Fe_2O_3)	5.70
4	Alumina ($Al_2\ O_3$)	22.08
5	Lime (C_a0)	0.47
6	Magnesia (Mg0)	0.23
7	Potash (K_20)	0.66
8	Soda (Na_20)	0.10
9	Loss	8.61

Source: Oyeoku (1988) the nature of Clay

Having explored and analysed the various clay samples, the independent layout earthen ware clay and the coal mine fire clay, all located in Enugu were found very ideal for the development and production of the bricks, while the independence layout clay would be used for the dense red bricks, the fire clay would be used to produce insulating and refractory bricks.

Line blend Test

Rhodes (1998:215) explains line blend which establishes a series of variation or mixes between two samples. A line blend test was carried out for the mixtures of fire clay and sawdust see table V.

Table V

Sample	A	B	C	D	E
Fireclay	30	40	50	60	70
Sawdust	70	60	50	40	30

For each samples, two test bars were made and labelled A to E to find out the best combinations. The first sets were fired to 1200^0c while the other batch was fired to 1300^0c. The following results were recorded.

Table VI

Series I	A	B	C	D	E
Dry shrinkage	4.5%	4.5%	5%	4%	4%
Plasticity	Good	Good	Good	Good	Good
Total shrinkage	11.5%	12%	13%	12.5%	11%
Absorption at 1200^0c	2.5%	2.5%	5%	5%	3%
Warping/cracking	None	None	None	None	None

Series I	A	B	C	D	E
Dry shrinkage	4.5%	4.5%	5%	4%	4%
Plasticity	Good	Good	Good	Good	Good
Total shrinkage	11.5%	1.2%	13%	12.5%	11%
Absorption at 1200^0C	2.5%	2.5%	5%	5%	3%
Warping/cracking	None	None	None	None	None

The 'C' combination of 50-50 was found to be best in the series and was used for the production of insulating bricks.

Kiln Properties and Design

There are several basic rules to consider when designing kilns, to be able to reach the necessary temperature for a firing. These rules are based on practical experiences of past kiln builders. Compact cubic shapes prove to have advantages over long-low structures, or a tall narrow one. In deciding the kiln proportion and design, the researcher considered good circulation in the chamber, adequate burners and fire box; flue size and proportionate chimney for draught.

An evenly fired chamber from top to bottom is considered in kiln design and building. A simple cube shape seems best both from the packing point of view and for ease of firing.

The flue and chimney should be of good proportions and allowance made for changing the size of these. The height of a chimney is governed by the width and kiln size. A general rule for the chimney height required to induce the correct draught is 1 inch of stack width = 1 foot of stack height (or 2.5cm to 30cm).

For the horizontal pull, each 30cm of cross-draught (horizontal pull) needs 60cm of chimney height, in additions to the vertical pull. The imperial rule is 30cm of vertical chimney for every 1.05m of horizontal draught (Rhodes 1981). The chimney diameter is often equal to that of flue and if anything, on the large side. A down draught kiln needs a strong enough draught to clear the hot gasses and flame through the chamber.

Production and Procurement of Bricks

Bricks are clay or ceramic nits of building construction, the commonest shapes being a rectangle 9 x 4½ x 2¾ inches or 22.8 x 11.5 x 5.7cm. Their shapes and sizes could be altered to suit the user. A range of special shapes and sizes for arches, bevels and domes were moulded by the researcher. (See figs 1, 2 & 3).

Fig.1: The researcher making the bricks

Fig. 2: Straight bricks

Fig 3: Side skew

For the purpose of this research, three types of bricks were used dense red bricks, the insulating and refractory bricks. The insulating bricks are referred to as the 'hot face' insulating bricks while the refractory ones are known as the solid fire bricks. The 'solid fire bricks' are made basically from fire clay and grog. They are hard, dense, volume stable and shall withstand various temperatures, while the 'hot face' insulating bricks are made from fire clay, and sawdust. This gives them a cellular composition, like that of a natural brick, with their good insulating qualities and the ability to withstand high temperatures. The dense red bricks were produced for the outside course.

Production of Insulating and Dense Bricks

All the bricks produced were manually done using wooden moulds of different shapes while some were cut into their shapes using saw, chisel and mallet.

Types of brick	Quantity
Straight standard dense earthenware	350

Straight dense refractory	50
Straight standard insulating	250
Arch	100
End skew	20
Side skew	20
Wedge	60
Circle brick	20

The raw clays were procured and exposed for months for it to weather. Both the red earthenware and grog were mixed, heaped up and left to soak for about seven days to enable water penetrate into the clay particles. Then it was trodden by foot to the right plastic consistency before moulding.

The fireclay after crushing was added sawdust of ratio 50-50 mixed thoroughly and moulded into various shapes. They were allowed to dry over months before firing. The bricks were fired to 1250^{o}c.

Brick Laying

Bricks were laid so that none of the joints were above each other. Just as in normal house building where each course over lays the next. This is also true of a double wall.

Brick walls are laid in alternating patterns so that joints are broken and the layers tied together (see figs 4 & 5).

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Fig. 4

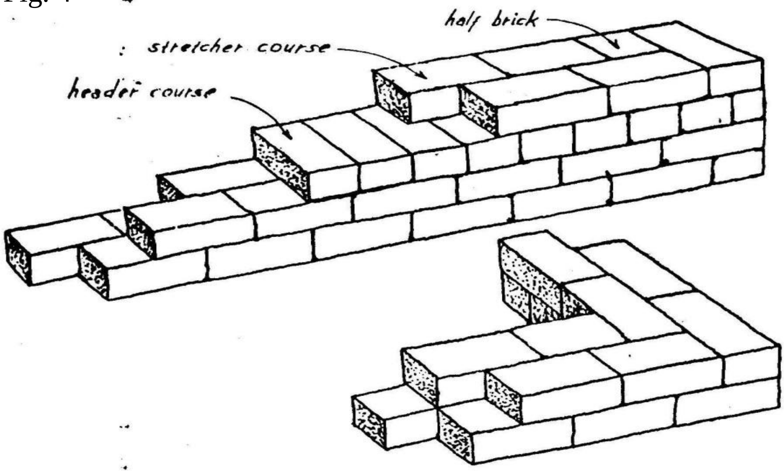

Fig. 5: Kiln building in progress

Mortar was used to fill the gaps, between the bricks and hold them properly in place. The mortar for laying the brickwork was made from mixing clay and sand (silica) or grog, in a ratio of two parts clay to one part sand. It helps to keep each course, level and straight.

The mixture of clay and sand is better used as a thick cream. The bricks were dampened before applying mortar so that the moisture is not sucked from the mixture, thus preventing adhesion.

Allowance was created in the structure for expansion, as the kiln is going to move and swell with the heat. A gap of ¼ inch to ½ inch was created between every tenth brick in a course. All the four walls were built working round by course at one go. It makes it to have a solid construction. Two external fire boxes were built in the kiln in opposite directions. The fire boxes were located parallel to the bag walls, and was well re-entered with suitable strong materials to withstand high temperatures. A double brick wall structure was firmly linked together from the inside course to the outside. The common bricks, refractory and insulating corrections were made with mortars.

Crones were established with care, using builders line, plumb, to keep the brickwork true, checking the level as the researcher builds. When half bricks were needed, the bricks were scored all round including the crones, and then cut across the second line with a brick chisel. Filling the bricks on concrete flood helped prevent spitting. In the case of the curved bricks a saw was used.

The door or wicket as it is called was constructed in such a way that it did not support the crown. It was given a generous size for ease of loading and off loading. The main arch is not quite such a simple job. A former needed in order to construct the arch in the correct position on the walls was constructed. The tools were two semicircular frame (templates) for the inside arch shape, 2 x 1 inch batons, hardboard, a square, a plumb-line, trowel and a masons hammer.

The former was placed in position between steel frame work to take up the thrust of the arch and brace the whole structure. Having done this, the researcher produced to lay up the arch in the same way as the

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walls, making sure that the joints were broken, the center course of wedges fits as tightly and neatly as possible. A brick harmer saw and wooden block was used to drive last course well home. The flue box from the kiln wall to the chimney was made as short as possible so that the efficiency of the chimney is not impaired by excessive horizontal pull. It was made of solid brick. The chimney was made of fire bricks to complete the total height. Care was taking to build an upright and straight structure and the metal pipe supported with iron and concrete into the foundation to prevent it from falling.

Fig. 6: The researcher's kiln completed

Firing

Perfect oxidation is hardly attainable in ceramic kilns. An analysis of the gases will always reveal the presence of some carbon dioxides. But for all flame or smoke an oxidizing effect on the ware will be achieved (Rhodes 1981:222)

Pre-heating, Firing

The kiln after loading with green wares is expected to be fired. It is the first firing and one has to go slowly since the kiln is full of moisture, the green wares and the damp walls.

The firing schedule is		**time**
1)	Water smoking period During this period atmospheric water is driven out	2 hours
2)	350 – 400^{0}C period Organic matter in the clay burns off	
3)	500^{0}C densification period End of water smoking-densification begins	
4)	573^{0}C densification period Physical change takes place. Silica expands Go slowly at this critical period	1 hour
5)	600^{0}C cherry red heat can now speed	
6)	Maturing period-depending on temperature and time to reach. Steady approach and care.	
7)	Maturing temperature Shut off the fire and allow cooling	
8)	Wait for 24 hours before opening it. Do not hurry; remove work when you can lift it with bare hands	

The Researchers Firing Test

Since the kiln has not been fired before, the chamber was loaded with green wares. The wares were packed together inside the chamber and fired to about 970^0C. The firing was done slowly in order to drive out the moisture inside the kiln since walls were damp. The firing lasted for six hours.

The firing was divided into three phases: pre-heating, full firing and cooling.

Pre-heating

Before preheating, the researcher poured 25 litres of kerosene into a pressurized tank, pressure pump was used to pump in air. A hose was connected from the tank to the burner. One burner was first used for pre-heating, and it went on stable and fine. After about two hours of pre-heating the spy hole was sealed. The firing went on gradually; this was to allow moisture to leave the kiln before full firing.

Full firing

Full firing started with the introduction of the second burner after two hours of pre-heating. The chamber was dull red and the tank was pressurized again to enable the burners atomize fully. The firing went on stable and fine and after three and half hours more, the firing was turned off.

Cooling

After the kiln was turned off, the spy hole was closed and the burners point also were closed. The kiln was left to cool gradually till the following day.

Result

The bricking door was taken down slowly brick by brick. A row or two at every ten to fifteen minutes to prevent sudden draft of cold air from striking on the wares that might cause a hair line crack or dunting. It was a successful firing because the wares came out fine. (See figs 7 & 8).

Fig. 7: Kiln Firing Chamber Showing bisque wares

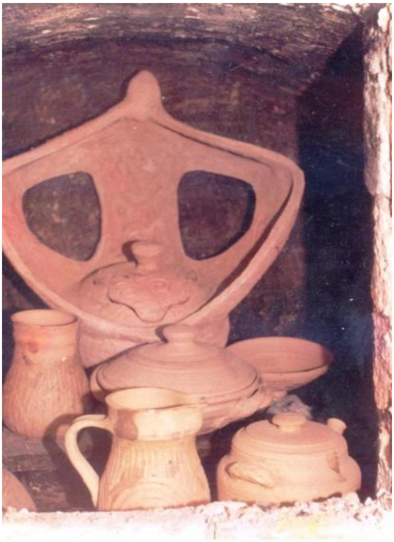
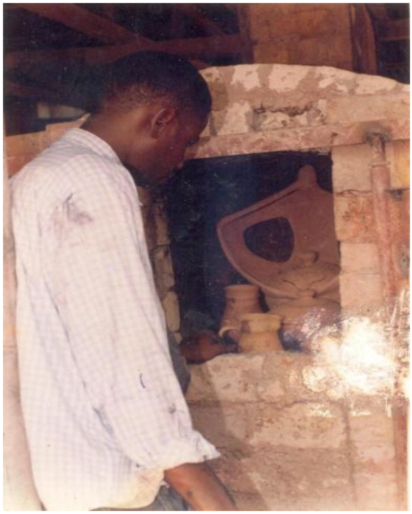


Fig. 8: The researcher opening the kiln after bisque firing



Conclusion

This research is a constructive attempt at using 100% locally sourced materials in Nigeria to develop a refractory body for kiln building, aimed at fulfilling the yearnings of most ceramists in developing countries, especially Nigeria.

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