DEVELOPMENT OF REFRACTORY BRICKS FROM LOCAL RAW MATERIALS

BY

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CERTIFICATION

We certify that this research work and the results obtained were carried out by Olunlade, Bankole Adeoye of the Department of Mechanical Engineering, Federal University of Technology, Akure and had been approved as meeting the requirement for the award of Master of Engineering Degree in Mechanical Engineering.

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Project Supervisor

14/3/2006

Date

DEDICATION

To Funmi, my wife

Dolapo

Moses

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I wish to thank a number of people who gave me support, inspiration and wonderful ideas through the process of studying, in the Federal University of Technology, Akure.

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ABSTRACT

Aluminosilicate refractory bricks for lining melting furnaces were produced from kaolin. Raw kaolin was processed and refined to remove impurities that may lower the refractoriness of the bricks. Part of this was thereafter used for the production of grog. Samples dimensioning 25.4 x 50.8 x 101.6mm were moulded from varying ratios of processed kaolin and grog mix using 18% tempering water. These were dried naturally in air and then in an oven at 120°C and fired at different temperatures ranging from 1000 to 1500°C. The samples were thereafter tested for such properties as apparent porosity, volumetric drying shrinkage, volumetric firing shrinkage, thermal shock resistance, cold compression strength and refractoriness. Results obtained indicated that the 20:80 grog:kaolin mix possesses good refractory properties for lining melting furnaces. Cost comparison of lining furnaces with bricks produced using existing and the new system was undertaken. The new system was found to cost 67% of the existing system.

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CHAPTER ONE

INTRODUCTION

1.0 Introduction

Refractories are non-metallic materials suitable for use at high temperatures in furnace construction. They are equally used to resist other destructive influences such as abrasion, pressure, chemical attack (corrosion and oxidation) and rapid changes in temperature (thermal shock). The longevity and performance of refractories under these conditions affect process economics, production capacity, product quality and safety. The group of materials mentioned above includes alumino-silicate refractories, which consist essentially of alumina and silica (high alumina, fireclay and kaolin refractories).

For the production of refractory bricks, a large percentage of grog is added to the highly plastic clay for the development of proper bonds. This hydrous aluminosilicate (Kaolinite group) that is used in making the refractory bricks can be found, most especially in the southwestern part of Nigeria.

Some research works have found that these local refractory clays are suitable for use as furnace lining materials in iron and steel industries. Borode, et al (2000) studied the properties of some locally sourced fireclays from Ikere-Ekiti, Isan and Ezinachi-Okigwe for high temperature applications. It was discovered that these clays have sintering temperatures of 1450°C, 1250°C and 1350°C respectively and could be used to melt metals whose melting points do not exceed these temperatures. Nnuka and Okunoye, (1991) studied the industrial potential of Ukpor clay. It was discovered that the clay has a sintering temperature of 1500°C. Addition of lime reduced the sintering temperature

though crushing strength increased from 399.29kg/cm^2 in bricks with no flux addition to 930.93kg/cm^2 in bricks with 5% flux.

Blending of Nigerian refractory clays and other refractory materials has been suggested by some works. For instance, Hassan, (2000) studied the effects of sawdust, graphite and asbestos on insulating and dense properties of refractory bricks. It was discovered that the addition of sawdust and graphite increased the apparent porosity of firebricks with attendant reduction in thermal conductivity. Addition of sawdust and graphite however led to poor cold compression strength; 7.69MN/m^2 in bricks without sawdust to 0.9MN/m^2 at 20% level. The work of Borode, et al (2002) on the production of refractory ramming mass by the blending of fireclay, silica, mica, and bentonite and calcium aluminate cement showed that with proper control of properties through blending, refractories with a wide range of porosity and crushing strength could be achieved with excellent thermal shock resistance.

One of the major factors affecting the cost per tonnage of foundry products is the cost of refractory bricks used in lining the shell of the furnaces. A large percentage of refractory bricks used in the Nigerian foundry industry are imported. Due to the recent downturn in the Nigerian economy, importation of refractory bricks using scarce foreign exchange is having a significant effect on the price per ton of products produced using them. This therefore competes for scarce foreign exchange with a negative effect of high cost of product. A sizeable amount of these bricks are used in metallurgical plants, cement industries and power generating plants. Thus there is the need to do further work on the development of local refractory bricks. From the foregoing, there is therefore a

need to develop a comparatively cheap refractory brick appropriate for melting furnaces within the country, using largely, local raw materials.

1.1 Objective of the Project

The objective of this project is to:

(i) Develop a comparatively cheap refractory brick appropriate for melting furnaces within the country, using largely local raw materials.

(ii) Develop refractory bricks for foundry works from Ijapo clay.

(iii) Valid the result of the development using different grog: kaolin mix, with cost reduction as an underlining factor.

CHAPTER TWO

LITERATURE REVIEW

2.1 Refractories

Refractories are thermal insulators that can withstand a very high temperature and attack in the severe conditions of working. They are heat resistant materials that are used to insulate and protect other materials and components from heat-related damage, as well as from abrasion, pressure and chemical attack (Grahl, 2004). As shown in Fig. 2.1, they are composed of large refractory aggregates and or grog held together by a bonding matrix. The microstructure also consists of pores, which arise from the firing of the refractories, as there cannot be 100% densification of the materials. The pores serve as thermal insulators.

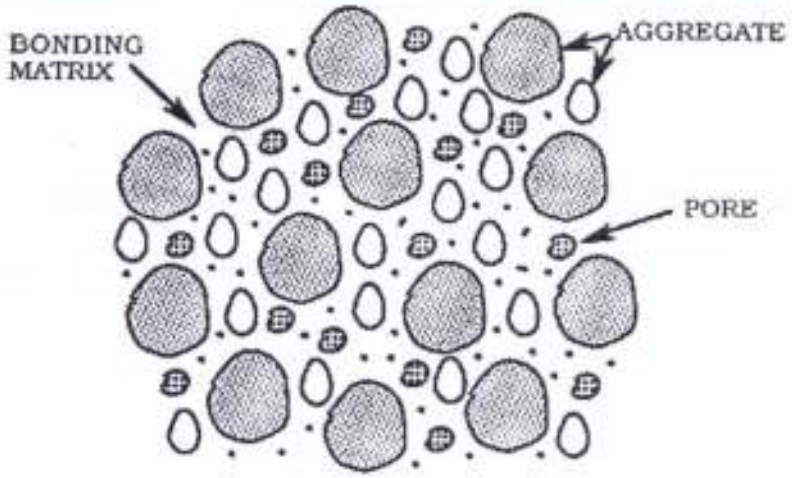


Fig. 2.1 Refractories Microstructure (Semler, 2002)

They are used in lining of furnaces, kilns, nozzles for pouring molten metal, heat exchangers, driers, e t c.

2.2 Classification of Refractories

Refractories can be classified based on chemical composition and shape.

2.2.1Classification based on chemical composition: These include:

(i) Acidic Refractories

These are refractories containing appreciable amount of silica (SiO_2), an acidic oxide, which reacts at high temperature with basic refractories, slags and fluxes. Refractories in these categories include silica refractories and aluminosilicate refractories.

Aluminosilicate refractories vary widely in their chemical, physical and mineralogical characteristics, depending on the nature and proportion of silica and alumina clay minerals present therein. As such they fuse over a wide range of temperature. The free silica lowers the fusion points of these refractories. Their raw materials occur either as natural rock or can be obtained as a prepared mass.

The silica refractories consist mainly of silica and must be low in metallic oxides and alkalis. The common forms in which their raw materials are available include rock, prepared mass, electrically fused quartz, quartz sand (ganister), and quartzite. They contain up to 97% silica with less than 0.3% alkalis. Alumina content ranges up to 10%.

(ii) Basic Refractories

These are mainly composed of CaO and MgO or a combination of both. They react with acidic refractories, slags and acids at high temperatures. They include magnesia (MgO), which is traditionally prepared from magnesite ($MgCO_3$) and having a refractoriness of

2888°C (Gilchrist, 1977). Dolomite ($CaCO_3.MgCO_3$) is another basic refractories with wide application. Lime (CaO) usually prepared by calcining $CaCO_3$ have a melting point of 2575°C. However, it cannot be dead-burned to become inert to water and therefore its use is restricted to platinum metallurgy. (Gilchrist, 1977)

(iii) Neutral Refractories

Neutral refractories are neither acidic nor basic. They resist attack from both acidic and basic materials. They include (i) carbon refractories – i.e. graphite, charcoal and coke (ii) artificial refractories like zirconium carbide, titanium carbide and silicon carbide (iii) refractory metals – tantalum, thorium, titanium, tungsten, vanadium and zirconium. Such materials are also used to replace basic refractories where the corrosive action is strong. Aluminosilicate refractories are sometimes classified as neutral refractories but they show acid reaction when exposed to basic slags.

Carbon refractories have a very high refractoriness, high thermal conductivity and non-melting characteristics. They are manufactured from coke and graphite, with tar or pitch as the bond material.

(iv) Special Refractories

Advancement in technology has called for the use of expensive materials for the manufacture of refractories to suit furnaces used for the production of rare and costly metals. These are referred to as special refractories. They are used for other special purposes involving very high temperature and appreciably no contamination of the materials being produced. Special refractories involve special production process and

purer raw materials and hence their use for common applications is prohibitive because of cost. Some of the important special refractories include Zirconia (ZrO_2), Zircon ($ZrSiO_4$), Silicon Carbide (SiC), Thoria (ThO_2), Beryllia (BeO), Sillimanite, other pure oxides like Al_2O_3, MgO and electro-cast refractories of mullite, magnesia and mixtures of chromite, bauxite and magnesia.

(v) Cermets

This is another class of special refractories, which are combinations of a metal or an alloy and non-metal such as an oxide, carbide, nitride or boride. Their marked high strength and resistance to temperatures make them suitable for use in special and more recent applications like those in space vehicles, missiles and nuclear energy plants.

(vi) Insulating Refractories

These are highly processed refractories with lower thermal conductivity and high thermal insulation properties suitable for minimizing heat losses and maximizing heat conservation in a furnace. They are produced from fireclay, kieselguhr or asbestos. Ceramic fibers and wool are used for high temperature insulation. Ceramics also belongs to this class of materials.

2.2.2 Classification By Shape

According to this method of classification, they are either shaped or unshaped.

(i) **Shaped**

These are shaped refractories of different compositions and shape, which depends on application. They include fireclay bricks, high alumina bricks, insulating firebricks, mica and insulating bricks.

(ii) **Unshaped**

These include the monolithics, castables, mouldables and rammables. The castable (poured), plastic (rammed) or blown (spray, foamed) forms of refractories are generally superior to laid up, dipped or refractory bricks construction because they are less prone to leakage, and they provide extended service life. Monolithic refractories are suitable for walls that must be gas tight. They have lower thermal expansion than most refractory bricks. Whatever small expansion occurs can usually be absorbed by the support. Therefore, unlike the refractory bricks, monolithic refractory walls do not require clearance for thermal expansion. Clearance required for bricks construction may allow passage for furnace gas leaks out or air into a furnace. The superior sealing capability and reduced expansion of monolithic refractories make them suitable for higher furnace pressures and temperatures.

2.3 Process of Refractory Bricks Production

Manufacture of refractories involves various steps in which natural refractory raw materials not directly suitable for use are converted into refractories of high quality. The various steps involved in the manufacture of refractories are as illustrated in Fig. 2.2 and described as follows: (Chesti, 1986)

(i) Crushing and Grinding

The as-mined material is crushed and ground to the proper particle size desired for the manufacture of bricks. Different equipment used for this purposes include various types of crushers, pulverizers, hammer mills, and ball mills. The ground materials are then graded on shaking tables and screens to obtain the desired particle size needed for refractories manufacture.

(i) Pre-Treatment

The principal treatment given to the material is basically firing or calcination at high temperatures for considerable periods of time. This brings about the complete mineral conversion and hence stabilization of the materials. Fireclay consists of numerous hydrous aluminosilicate minerals which on heating break down to several constituents. These constituents tend to form mullite ($3Al_2O_3$. $2SiO_2$) which is the only compound of silica and alumina stable at high temperatures. X-ray analyses have shown that mullite begins to form at about 1000^0C. At increasing temperatures the formation of mullite is accelerated. Strength at high temperatures, resistance to slag action and many other useful properties of fireclay refractories depend on the development of mullite and properties of the glassy bond. Lee and Rainforth (1994).

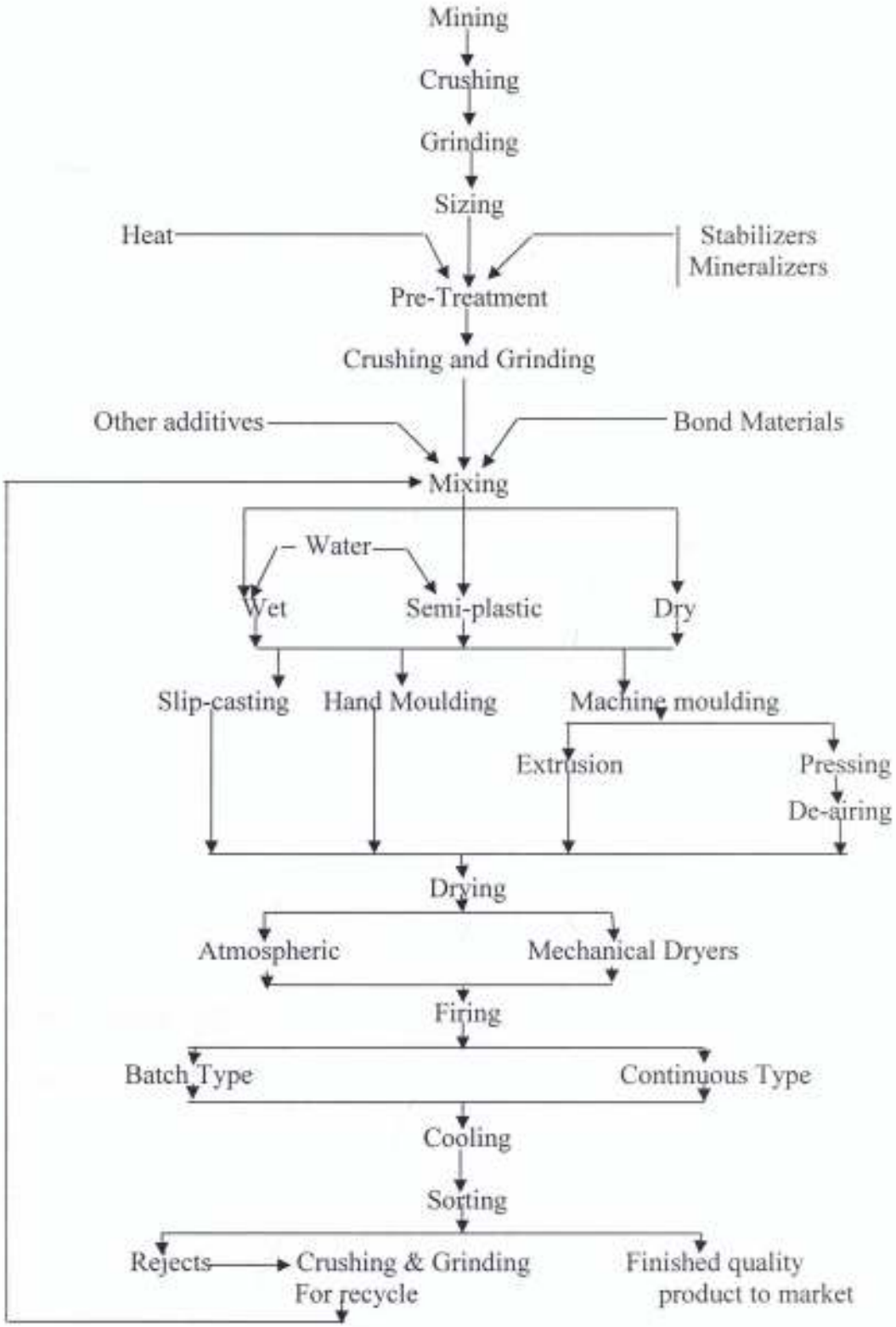


Fig. 2.2 Process of Refractory Bricks Production
Adapted from: Chesti, 1986

(iii) Mixing

Mixing is done to facilitate even distribution of fine and coarse particles in the whole mass. Pre-calculated amounts of water, binding materials, additives, and mineralizers i.e. stabilizers, grogs etc are added. The mass is mixed thoroughly to ensure a product of uniform composition and uniform distribution of fine and coarse grains, plastic and bond materials for easy moulding and development of best possible properties in the fired refractories.

Mixing can be done wet, semi-plastic or dry. 14-20% water is used in wet mixing (Chesti, 1986). Semi-plastic mixtures have lower percentages of water while the dry mixtures include non-plastic basic mixes and dry clay mixes containing less than 5% water. Mixing with so little water is difficult. Water as a fine spray or mist is used to achieve proper mixing. Semi-plastic and dry mixtures require high pressure for moulding and are therefore machine pressed.

(IV) Moulding

Moulding into desired shapes is carried out either manually or by some mechanical means (hand moulding or machine moulding). Machine moulding is done by pressing or by extrusion. Hand moulded refractories have lower density and strength values than mechanical moulded refractories. Dense and strong refractories not very intricate shapes are produced by machine molding processes.

When high moulding pressure is used, air is liable to be trapped which could cause laminations. De-airing decreases laminations and cracks in mechanically moulded refractories and thereby increases their density and strength values.

Slip casting is another method of moulding refractories of hollow and other special shapes from very fine powders. A colloidal suspension of the materials is poured into a Plaster of Paris mould, which absorbs the water and causes deposition of a uniform layer of clay on the mould wall. When the desired clay thickness is deposited, the extra mixture in suspension is poured out of the mould resulting in hollow refractories with irregular internal contours.

Powder pressing is another forming process for refractories which involve compacting dry or slightly damp refractory powder mixtures in metallic dies, using sufficiently high pressures to produce dense and strong refractory shapes.

(v) Drying

Moulded refractories are dried to remove moisture and increase their green strength. Drying rate is kept to a minimum to avoid higher shrinkage and crack formations. Drying can be carried out in shades on large drying floors or floors heated by waste gases from kilns. Fireclay refractories are liable to undergo maximum shrinkage on drying and therefore drying rate has to be very slow to avoid crack formation and ensure a quality product.

(vi) Firing

Firing follows the drying process. This involves dehydration of the dried refractory and its subsequent vitrification and development of stable mineral forms in them, and formation of ceramic bonds necessary for development of high crushing strength in the finished product (Chesti, 1986). Firing of refractories also leads to its densification by decreasing the porosity levels. Usually densification occurs as a result of firing whereby one component must form a bond to glue the large grains together either by reaction of the clay to give a small amount of liquid which cools to form a glassy phase or by decomposition of a carbonaceous binder to form a carbon bond. Refractories are never fired to 100% densification because the presence of porosity is required for thermal insulation. Firing may involve as much as 30% shrinkage in the refractories. This sets great stresses in them which results in the distortion of refractory shapes. To avoid such situations, it is necessary to carry out a pre-stabilization of the raw materials.

Firing is carried out in kilns, which may be batch type or tunnel type. Continuous tunnel kilns are suitable for mass production. In this case, dried refractories are charged from one end and fired, and products at near room temperatures are discharged from the other end.

2.4 Clays

Clays are products of decomposition and alteration of feldspathic rocks (Grahl, 2004). They consist of a mixture of particles of different sizes and widely differing physical, chemical and mineralogical properties. The non-plastic portion consists of altered and unaltered rock particles of which the most common and abundant substances

are quartz, micas, feldspar, iron oxides and calcium and magnesium carbonates. Organic matter usually is also present in greater or lesser amounts. The degree of contamination of clay can be determined by the chemical analysis of clay. For example, higher silica content than the corresponding proportion in the clay minerals indicates contamination with quartz. The presence of alkalis implies the presence of contaminants like feldspar and mica. These together with bivalent oxides and iron oxides reduce refractoriness in bricks by facilitating the formation of flux. The essential constituents of clays are hydrated silicates of aluminium. There are several types of this but the most important and widespread are the kaolinite group, Al_2O_3-$2SiO_2$-$2H_2O$ and montmorillonite group (Mg.Ca)O-Al_2O_3-$5SiO_2$-H_2O.

2.5 Clay Minerals

The clay minerals consist of hydrated aluminium silicates that are fine grained and usually have a plaity-habit (Mikhailov, 1987). The properties exhibited by clays are dictated by their main functional group called clay minerals which are aluminosilicate-containing hydroxyl groups.

The clay minerals include kaolinite, which is the most common, and its structural formula is $Al_2O_3.2SiO_2.2H_2O$. It forms plates 0.1 to 0.3μm in size and about 0.005μm in thickness. (Mikhailov, 1987) .Kaolin belongs to this group. The term "kaolin" describes a type of clay which fires to white colour and has a Pyrometric Cone Equivalent (PCE) of 34-35. It usually contains less than 2% alkalis and smaller quantities of iron, lime, magnesia and titanium. (Grahl, 2004). Because of its purity, kaolin has a high fusion

point and is the most refractory of all clays. Kaolin alone is widely used in casting sanitary ware, ceramics and refractories.

Kaolin deposits are designated as either primary or secondary deposits. Primary deposits or residual kaolins are those white burning clays formed by weathering, in place of feldspathic rocks, pegmatite, granites and the like and found in locations of the parent rock. Secondary or sedimentary kaolins are those that were formed by weathering, then carried by water and re-deposited in another area.

Montmorillonite group is another type of clay minerals having the structural formula $Al_{12}.(SiO_2)_5.(OH)_2$. It has a 3-layered structure and having particles finer than that of the kaolinite group (up to 60% are below 0.1μm). Montmorillonite is characterized by string bonding and swells when wetted with water. Bentonite is a typical example in this group and it contains more than 80% montmorillonite.

Illite is a group of micaceous clay ranging between montmorillonite and muscovite in composition and structure. The structural formula of Illites is $K_xAl_4(Si_{8-x}Al_x)O_{20}(OH)_4$ where x ranges between 1.0 and 1.5. (Mikhailov, 1987)

2.6 Plasticity in Clays

The clay minerals – kaolinite and montmorillonite, have microscopic plate-like structures which are believed to be solely responsible for their plasticity (formability when wetted with water). An extremely high content of fine particles is characteristic of very plastic clays. The finest fraction, which also is quite small, contains the clay suspensoids or colloids, which are responsible for the plasticity. Too high a content of the so called clay substances can make the material excessively plastic, which renders it

sticky and difficult to work. Other important factors in plasticity are the amount, size, relative proportion of sizes, shape and other characteristics of the granular material, and the amount and character of soluble salts (electrolytes) and organic materials present. The more plastic a clay is, the more water it requires to make it workable. And the more gradual the water loss during its drying because of its extensive capillary system. High plasticity clay will shrink more and will be more likely to crack.

The grain fineness of clay influences not only its plasticity but also its properties such as drying performance, drying shrinkage, warping, and tensile, transverse and bonding strength. The greater the proportion of fines, the slower the drying rate, the greater the shrinkage, and the greater the tendency to warp and crack during drying. Clays with high fines content usually are mixed with coarser materials to avoid these problems.

2.7 Binders

Binders are substances, which serve to hold low, green strength ceramic materials and bodies together and give them sufficient bonding for handling and machining in all pre-firing stages of manufacture. Their use reduces loss of ware and, in many cases, makes fabrication, possible. A satisfactory binder should have a combination of attributes such that it would impart high strength, be free from combustible residual matter, non-sticky to die parts, nor pick up atmospheric moisture and be readily dispersible as solution or emulsion. It should also not unduly increase the final cost. Materials used as binders include clays, natural gums, dextrin, pitch, asphalt, sodium silicate, glues, starches, lignin, cellulose derivatives and thermoplastic resins. These are used in varying

percentages but most do not exceed 5% of batch weight. (Grahl, 2004). Some of the binders could lower the refractoriness of bricks. For example sodium silicate will lower the sintering point of aluminosilicate refractories and borax should not be used in excess of 1% in the manufacture of silica bricks (Chesti, 1986). Addition of lime to clay up to 0.3% w/w could promote mullite formation and increase the refractoriness of the clay. Beyond this value may result in lowering refractoriness and spalling resistance. (Nnuka and Okunoye, 1991).

There are two main divisions of binders namely: organic and inorganic binders. Organic binders include emulsions, methylcellulose, hydroxypropyl, starches and dextrin. Inorganic binders are clays, cement, water glass, Plaster of Paris, etc.

2.8 Properties of Refractories

Refractories have different properties, some of which are common to all and others are specific to other applications. The important requirements of refractories to the users are as follows.

(i) **Good refractoriness at the operating temperature of the furnace/kiln:** Refractoriness of a material refers to the maximum service temperature to which a material can be put to use without softening. These vary from one material to another. The determination of the actual melting point of refractories is not possible as it extends over a range of temperature – perhaps over several hundreds of Celsius. Therefore, working temperature or the service temperature is always quoted for these materials. The softening point of fireclay refractories varies widely depending upon the type of clay; their alumina content and the type of grog used. This corresponds to Pyrometric Cone

Equivalent values of Orton 31 to 34. (Chesti, 1986). If the chemical analysis of a clay is available, then, clays with over 30% Al_2O_3 and less than 5% in total of Fe_2O_3, CaO, MgO, Na_2O and K_2O would probably have a PCE of at least cone 26 (1570°C) (Gilchrist, 1977). The PCE increases with Al_2O_3 content of the clay. Clays with 40% Al_2O_3 would probably give a PCE value of Cone 33 or 34.

(ii) **Ability to maintain shape and strength at the service temperature:** This is measured by the volumetric shrinkage after firing and cold crushing strength. The cold crushing strength is required to assure the user of the refractories that it will not fail in compression during service. It also gives an indication about whether the bricks have been fired properly or not and that they would transport readily without damage to corners and edges. The strength depends on several factors, which includes porosity, thoroughness of firing of the bricks and grog particles distribution, which help in arresting cracks.

(iii) **Good thermal conductivity:** This is expected to be low if the refractories have to provide the proper insulation expected. Thermal conductivity depends on the porosity of the material. Porous refractories have air spaces in the pores, which act as an insulator. The entrapped air increases with porosity of the refractories and hence thermal conductivity decreases. Thermal conductivities of some refractories are given in Table 2.1.

(iv) **Electrical conductivity:** This depends on the use to which the refractory has to be put. Graphite and refractory metals are good electrical conductors. Refractories used for lining electric furnaces should have very low electrical conductivity. The property

Table: 2.1 Thermal Conductivities of Refractory Materials (Chesti, 1986)

	Room Temperature (e.g.s)	**300°C**	**700°C**	**1100°C**
Silica	-	0.003	0.004	0.005
Firebricks	0.002	0.002	0.002	0.003
Silllimanite	-	0.003	0.004	0.004
Magnesite	-	0.003	0.004	0.004
Chrome	-	0.004	0.004	0.005
Chrome Magnesite	-	0.005	0.005	0.004
Insulating Firebrick	0.0007	0.0006	0.0006	0.0008
Kieselguhr	0.0001	0.0003	0.0004	-
Asbestos	0.00008	0.0001	0.001	-
Slag wool	-	0.0001	0.0001	-
Carbon	0.1	-	0.005	0.008
Graphite	-	0.21	0.12	0.08
Carborundum	-	-	0.03	0.02

depends on the porosity of the refractories, as porous refractories are less conductive.

(v) **Porosity:** Porosity is defined as the total fraction (or volume %) of pores in a porous material. The pore could either be open or close. When open, the space in between bonding matrix and the aggregate can still allow movement of fluid. Whereas air is already trapped in closed pores and no movement is possible. Different types of porosity existing in refractory materials include:

(a) **Apparent or open porosity**, which is the volume of the open pores in a material divided by the bulk volume.

(b) **Closed porosity**, which is the volume of closed pores within the material divided by its bulk volume.

(c) **True porosity**, which is the volume fraction of the open pores to the closed pores. Before sintering of a material, virtually all pores in the refractories are opened but upon firing the volume fraction of the porosity decrease and many more pores become closed. Low porosity gives better resistance to abrasion, slagging and attack by gases, but gives a very poor spalling resistance. Porosity values are usually about 20-25%.

(vi) **Ability to withstand thermal shock due to temperature fluctuations:** Refractories subjected to alternate cycles of heating and cooling must not spall or crack and crumble to pieces. On heating, the refractory grains expand and result in compression in the structure of the refractory, which may be sufficient to cause shear failures.

Therefore, refractories having low thermal coefficient of expansion and coarse textures have increased resistance to sudden changes in temperature.

(vii) **Ability to withstand abrasion:** This is important in furnaces where the refractories lining come in contact with the charge. Such furnaces include the rotary furnaces, where the charge rolls on the lining and, cupolas and blast furnaces where the descending solid charge results in abrasion or wearing away of the lining. Therefore, in these circumstances it is necessary to use a dense, fine-grained and wear resistant refractory lining.

(viii) **Ability to withstand erosion from the charge:** Erosion of the lining takes place when molten metal or gas, carrying dust and slag particles, strike against the refractory lining resulting in chipping off of particles from it. Refractories for applications in such areas must be able to withstand such erosions.

(ix) **Resistance to slag attack:** The resistance to the action of slag is one of the most important qualities of refractories and depends on the nature of slag and refractories. At high temperature a slag always attacks refractories. Slag action also occurs if the slag contains constituents capable of forming mixtures of new compounds with the refractories. The film of slag in contact with the brick dissolves some of the refractories however small an amount it may be. Its composition gets altered resulting in increase or lowering of melting point of the slag. If its melting point gets raised, the slag film becomes highly viscous, sticky, inactive and incapable of dissolving the refractories any

further. It thus protects the refractories wall as long as the said film does not get detached from the refractory surface and get dissolved in the main slag. An acidic slag will dissolve a basic lining and a basic slag will dissolve an acidic lining. The choice of refractories therefore depends on the type of slag that may be generated. Slag attack also depends on the smoothness of the refractory walls. A dense and well-vitrified refractory material will present a smooth surface to the slag and the effect of slag will be reduced. Rough and porous surfaces present increased surface area to the action of slag and thereby accelerate the slag attack. Fusible glass of refractories is more liable to be dissolved in the slag than the refractories grains. Defective joints and cracks in the refractory structure also accelerate the rate of slag attack.

2.9 Testing of Refractories

Refractories have to be tested for their suitability in service. As such some of the following tests have to be conducted on samples taken for refractory bricks before usage.

(i) **Cold Compression Strength Test:** This is carried out by a simple compression strength test called cold crushing strength test. It serves as a guide to refractories users that the brick would not fail in compression during usage. It is also an indication of whether the brick has been properly fired or not. The cold compression strength is usually carried out by placing the test piece between the two plates of a compression tester. This is followed by the application of a uniform load to it. The load at which a crack appears in the refractories sample is noted and divided by the surface area. The value obtained represents the cold crushing strength of the sample.

(ii) Refractoriness Test: This test is carried out to determine the softening point of refractories. It is not generally practicable to determine the melting point of refractories. Melting of refractories takes place over a range of temperature, often over several hundreds of Celsius. The test for refractoriness is done by comparing the sagging of a standard "cone" of the material with that of a standard Seger or Orton cone, when they are heated together at a standard rate in an oxidizing atmosphere until the test cone bends over. (Gilchrist, 1977). The number of the best matching Seger cone is quoted as the refractoriness of the brick; or its nominal melting point refered to as the Pyrometric Cone Equivalent (PCE) temperature. Table 2.2 gives the temperature equivalents for the Pyrometric Cones on the Seger and the Orton Standards.

(iii) Thermal Shock Resistance

This is measured by a spalling test. Various tests used in determination of the thermal shock resistance of a brick involve heating either a brick or a section cut from the brick, slowly up to a working temperature, and then cooling it rapidly for 10mins in a jet of air or on a steel plate, then reheating for 10mins in the furnace held at that temperature. This is repeated until a piece of the brick becomes detached or a crack appears. The number of cycles of repeated heating and cooling prior to failure is noted and taken as a function of the thermal shock resistance of the brick. A brick surviving 30 cycles is claimed to be very good and quoted as having a spalling resistance of +30cycles.

The result of a spalling test must depend on at least four properties of the brick. They are the thermal conductivity, which determines the temperature gradients set up under the test conditions, the coefficient of thermal expansion, which determines the

strain induced by these thermal gradients, modulus of elasticity and the shear strength of the brick substance.

Table 2.2: Temperature Equivalent for Pyrometric Cones **(Hlavac, 1983)**

Cone Number	**End Point (°C)**	
	Seger Cone	**Orton Cone**
12	1350	1337
14	1410	1398
16	1460	1491
18	1500	1522
20	1530	1564
26	1580	1621
28	1630	1646
30	1670	1665
32	1710	1717
34	1750	1763
36	1790	1804
38	1850	1835
40	1920	1885
42	1980	2015

(iv) Refractoriness Under Load

The objective of this is to determine the maximum temperature at which the brick could be used under compressive load. It is a measure of the hot strength of the brick. The specimen is heated in a carbon granule furnace at a standard rate (10°C/min) and a record of its height made, preferably by automatic plotting, until the test piece collapses or sinks to 90% of its original length. The hot strength of refractories depends on the structure of the brick as well as on its melting characteristics. This hot strength may persist beyond the solidus temperature of major constituents since re-crystallization takes place during firing to form a three dimensional network of interlocking crystals of high melting point. This allows for rigidity to be maintained even while a part of the material is molten in its interstices.

(v) Shrinkage Test

This determines the average shrinkage after firing. It could be linear or volumetric. Measurement of the dimensions of the test pieces is taken before and after firing. The resulting change gives the percentage shrinkage as stated below:

$$\% \text{ Shrinkage} = [\text{Initial Dimension}/\text{Final Dimension}] \times 100\% \qquad 2.1$$

(vi) Porosity

This could be determined in two ways:

(a) Evacuation Method: The test piece is dried at 110°C in an oven to a constant weight. It is thereafter immersed in water for 5-6hrs to soak and weighed while still suspended in

water. The soaked specimen is also weighed while suspended in air. The apparent porosity is then calculated thus:

$$P = \frac{W-D}{W-S} \times 100\% \qquad 2.2$$

Where P= apparent porosity

W= weight of soaked specimen suspended in air

D= weight of dried Sample at 110°C

S= weight of soaked specimen suspended in water

(b) Boiling Point Method

The test piece cut from a burnt brick is dried in an oven at 110°C to a constant weight. The dried specimen is weighed in water while been freely suspended. It is then boiled for 2hrs in this position. The specimen is removed from water. Its weight in air, is measured and recorded.

The apparent porosity is thus calculated from

$$P = V_1/V \times 100\% \qquad 2.3$$

Where V_1= Actual volume of the open pores

=W-D

V= External volume of the specimen

=W-S

W= weight of boiled specimen in air

D= weight of dried brick at 110°C

S= weight of boiled specimen suspended in water

W= weight

(vii) Loss on Ignition

This determines the percentage weight reduction of the brick after firing. It is calculated from

$$LOI = W_i - W_f / W_i \times 100\% \quad 2.4$$

Where LOI=Loss on Ignition

W_i = Initial mass of sample

W_f = mass of sample after firing

(viii) Resistance to Slag Attack

This measures the ability of the bricks to withstand the chemical and abrasive action of the slag. There are several ways of testing refractories for slag resistance. Two of which are discussed hereunder.

(a) Running Slag Test: The resistance to slag attack is tested by heating the refractory to a temperature close to its service temperature. Powdered slag is then dropped on to the surface of the refractory bricks from where it runs through a groove provided for that purpose. The depth to which the groove becomes enlarged at the close of test is given as a measure of the resistance to slag attack of the refractories.

(b) Spray Test: In this test, the powdered slag is uniformly sprayed on a heated refractory surface under standard temperature and other working conditions. The extent of slag penetration is taken as a measure of the resistance of the refractory brick to slag attack.

CHAPTER THREE

EXPERIMENTAL TECHNIQUES

3.1 Materials and Preparation

3.1.1 Materials

The materials used for this research work consist of the following:

i Kaolin, from Ijapo Estate, Akure, Nigeria

ii Grog, prepared by firing the processed kaolin at 1300^0C

iii Bentonite

3.1.2 Materials Preparation

3.1.2.1 Preparation of Raw Kaolin

Raw kaolin was soaked in a large quantity of water for two weeks. The moist clay was then sieved through a fine mesh of <100μm to remove free silica and organic impurities, which may lower refractoriness of kaolin. Free silica combines with alkali and alkaline earth oxides e.g. CaO and Na_2O to form complex silicates at much lower temperature than the melting point of pure aluminosilicates (Adeoye, 1985). The pulp was left to settle down overnight. The settled clay was again subjected to a dewatering process. The clay was put in bags and pressure was applied on them for another 24hours. The slurry gotten from the dewatering process is dried naturally in air to reduce the water content. To ease the crushing process, the dried kaolin was dried further in an oven at 120^0C for 6hrs and then crushed, milled and sieved through 300μm.

3.1.2.2 Preparation of Grog

To prepare the grog, part of the processed kaolin was fired at 1300°C in a furnace for 3hrs. It was left to cool to room temperature. After cooling, it was crushed in a laboratory size jaw crusher. This was then milled in a ball mill until the powders was so fine to be sieved to desirable size range. The powder from the ball mill was then sieved for particle sizes ranging from 600-850μm, which were used in the experiments. The oversized particles were recycled for another round of milling.

3.2 Chemical Analysis of Samples

The chemical analysis of the processed kaolin and bentonite was done using the Atomic Absorption Spectrophotometer (AAS). The results obtained are presented in Table 4.1.

3.3 Experimental Procedure

Different percentages of Kaolin were mixed with 5% bentonite in a laboratory sand mixer. Mixing was done for 10mins in dry form before addition of water. 18% water was then added, and thorough mixing continued for another 20mins. This was done to impart the necessary green strength. The water content was just enough for the preparation of the green samples without having dry powders in the mix. The mixed material from the sand mixer was withdrawn for investigations.

Experiments were conducted to determine the optimum pressure required for the moulding of refractory bricks. Samples measuring 101.6 x 50.8 x 25.4mm were prepared for different moulding loads ranging from 100kN to 350kN. These were allowed to dry naturally overnight and later dried in an oven at 120°C for 2 hours (Ford, 1986). The

samples were later fired at a temperature of 1100°C in a Geotest high temperature reheating furnace model v-1509 furnace at the rate of 5°C/min for 3hrs as suggested by Chesti, 1986.

Apparent Porosity, volumetric drying shrinkage, and volumetric firing shrinkage and losses on ignition were measured for the samples.

Apparent Porosity

Apparent porosity was determined using the evacuation method. The samples were dried at 110°C in a muffle furnace to a constant weight. It was thereafter immersed in water for 6hours to soak and then weighed while still suspended in air. The apparent porosity was calculated using equation 2.2.

Volumetric Drying / Firing Shrinkage

Volumetric dimensions of the samples were measured before drying and firing. Measurements of the volumetric dimensions were again taken after drying and firing. The resulting change in dimension was applied in equation 2.1 to calculate the percentage shrinkage.

Loss on ignition

Initial weights of the samples were measured. After firing, the final weights of the samples were also measured. The loss on ignition (LOI) was then calculated using equation 2.4.

It was observed that the 300kN load (maximum on the machine) was enough to bring the apparent porosity of sample to 35.46%, which is closer to the normal value of less than 30% quoted by Gilchrist (1977) for aluminosilicate bricks. This pressure was therefore picked for moulding of samples for further investigations.

The effect of grog addition on the physical properties of the brick was studied. Experiments were conducted by mixing varying proportions of kaolin and grog. The grog was added in steps of 5%, with 5% bentonite to each mix as binder. Moulded samples using a load of 300kN were fired at 1100^{0}C and tested for physical and mechanical properties namely; linear firing shrinkage, volumetric firing shrinkage, apparent porosity, as described above. The cold compression strength and thermal shock resistance and refractoriness tests were also performed as described below.

Cold Compression Strength

The cold crushing strength test was carried out by placing the test piece between the two plates of an ELE tabletop Compression machine with hand pump and analogue gauge. This was followed by the application of a uniform load. The loads at which a crack appeared in the refractories samples were noted and divided by the surface area. The values obtained represent the cold crushing strength of the sample.

Thermal Shock Resistance

Spalling test was used in the measurement of the thermal shock resistance for the sample. In this test, the sample brick was heated slowly up to 1100^{0}C for 3 hours and then cooled rapidly for 10 minutes on a 1.63mm thick steel plate. It was then reheated for 10 minutes

in the furnace held at 1100^{0}C. This was repeated until a crack appeared. The number of cycles of repeated heating and cooling prior to failure was noted.

Refractoriness

This test was carried out on samples to determine the melting point of the refractories. The refractoriness test was carried out by heating the sample to a temperature of 1300^{0}C and thereafter brought out for visual examination. The withdrawal of sample from the furnace was carried out at an incremental interval of 50^{0}C to view the sample for element of fusion. But none of the samples fused at 1500^{0}C which is the maximum temperature obtainable on the furnace used.

The results obtained from these tests are presented in Table 4.3.

Experiments were further conducted on the 20:80 grog:kaolin sample. This optimum composition was chosen on account of enough cold compression strength good apparent porosity and linear and volumetric shrinkage. Studies were conducted on the effect of sintering temperature on the physical and mechanical properties of the samples made from these compositions. Properties such as volumetric firing shrinkage, apparent porosity, and cold compression strength were determined as described above. The results obtained are presented in Table 4.4.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Results

Measurements have been taken to characterize a local clay deposit at Ijapo, Akure with a view to determining its potential for manufacturing refractory bricks. Besides the determination of its chemical composition, it was subjected to various tests to determine its physical and mechanical properties. The results obtained are presented in Tables 4.1 to 4.4, as well as in Figures 4.1 to 4.11 and discussed under section 4.3.

Table 4.1: Chemical Composition of Materials

Sample / Chemical Compound	Ijapo Clay (%)	Bentonite (%)
Al_2O_3	38.00	37.05
SiO_2	43.33	54.01
CaO	0.23	0.42
Na_2O	0.92	0.86
MgO	0.22	0.69
Fe_2O_3	1.93	0.53
TiO_2	0.04	-
MnO	0.52	0.13
LoI*	15.21	6.31
TOTAL	**100.00**	**100.00**

*LoI = Loss on Ignition

Table 4.2: The Effect of Moulding Pressure on the Thermal Properties of Ijapo Clay

Pressure (KN)	Apparent Porosity (%)	Volumetric Drying Shrinkage (%)	Volumetric Firing Shrinkage (%)
100	46.82	3.57	35.56
150	40.62	2.56	30.27
200	38.57	1.97	22.43
250	37.08	1.60	20.96
300	35.46	0.94	19.0

Table 4.3: The Effect of Grog Addition on Thermal and Mechanical Properties of Ijapo-Clay Moulded At 300KN and Fired At 1100°C

Grog (%)	Cold Compression Strength (kg/cm^2)	Apparent Porosity (%)	Linear Firing Shrinkage (%)	Volumetric Firing Shrinkage (%)	Refractoriness (°C)	Thermal Shock Resistance (No. of cycles)
0	**865.27**	**35.46**	**4.44**	**19.0**	**>1500**	**+30**
5	764.09	38.34	4.44	11.29	>1500	+30
10	626.98	39.40	4.44	10.87	>1500	+30
15	569.44	39.85	3.33	8.87	>1500	+30
20	528.78	40.56	3.33	8.87	>1500	+30
25	490.19	41.28	3.33	5.37	>1500	+30
30	451.41	40.22	3.33	3.59	>1500	+30
35	425.35	41.51	2.22	2.50	>1500	+30

Table 4.4: The Effect of Sintering Temperature on the Physical and Mechanical Properties of Clay-Grog-Bentonite System

Sintering Temperature (°C)	Cold Compression Strength (kg/cm^2)	Linear Firing Shrinkage (%)	Volumetric Firing Shrinkage (%)	Apparent Porosity (%)
1200	653.06	5.055	13.30	35.0
1300	712.33	9.170	22.15	27.0
1400	866.99	11.100	24.46	22.0
1500	887.95	11.92	29.89	14.0

4.1 Discussion

4.1.1 Effect of Moulding Pressure on the Physical Properties of Ijapo-Clay

The effect of moulding pressure on the physical properties of the processed Ijapo-clay was studied to ascertain a suitable moulding pressure for refractory bricks production. Fig. 4.1 presents the apparent porosity of the brick, which decreases with increase in moulding pressure. Fig. 4.2 shows the effect of moulding pressure on the volumetric drying shrinkage and volumetric firing shrinkage of Ijapo-clay, both of which decreases as the moulding pressure increases.

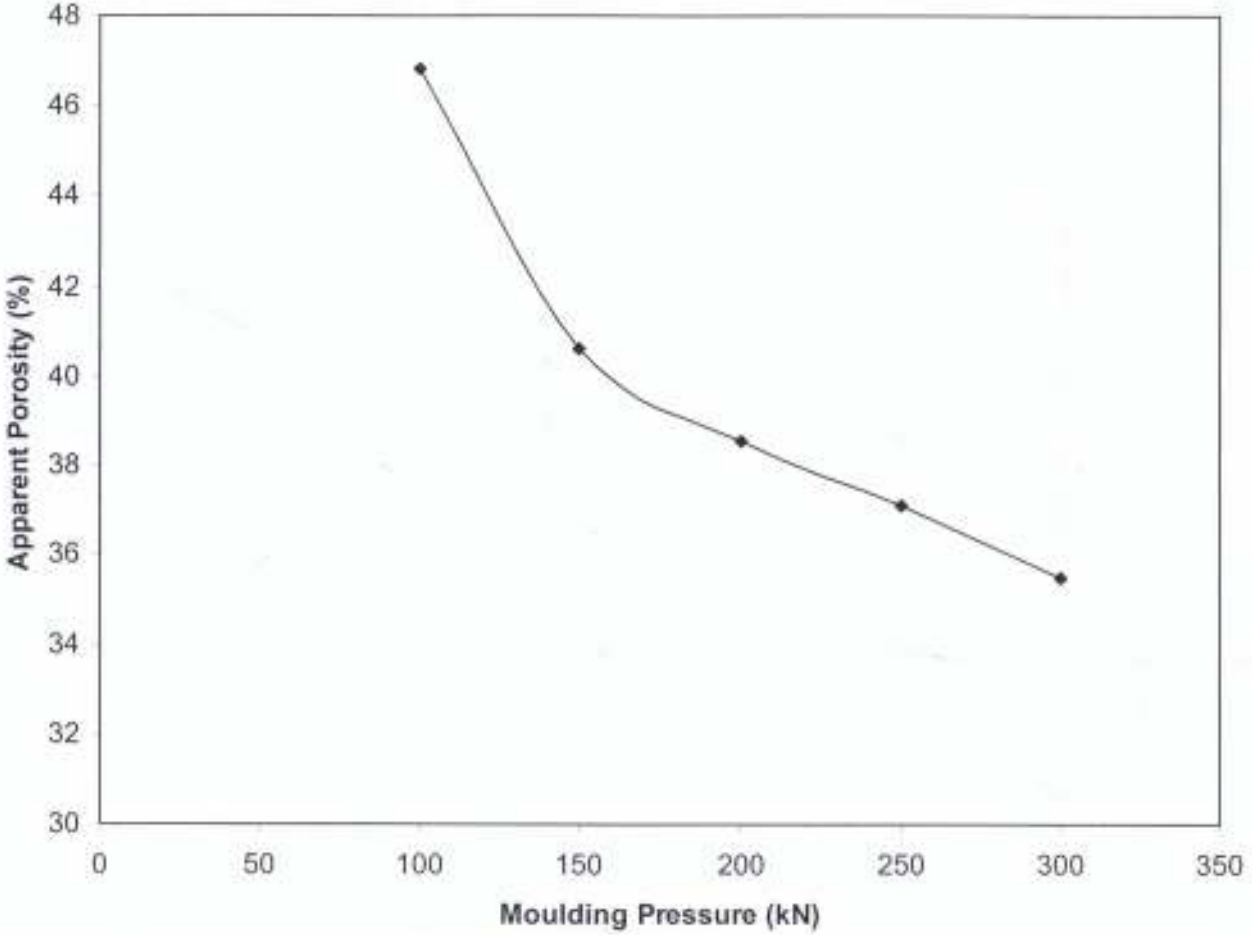


Fig. 4.1: The Effect of Moulding Pressure on the Apparent Porosity of Ijapo clay Bonded with 5% Bentonite

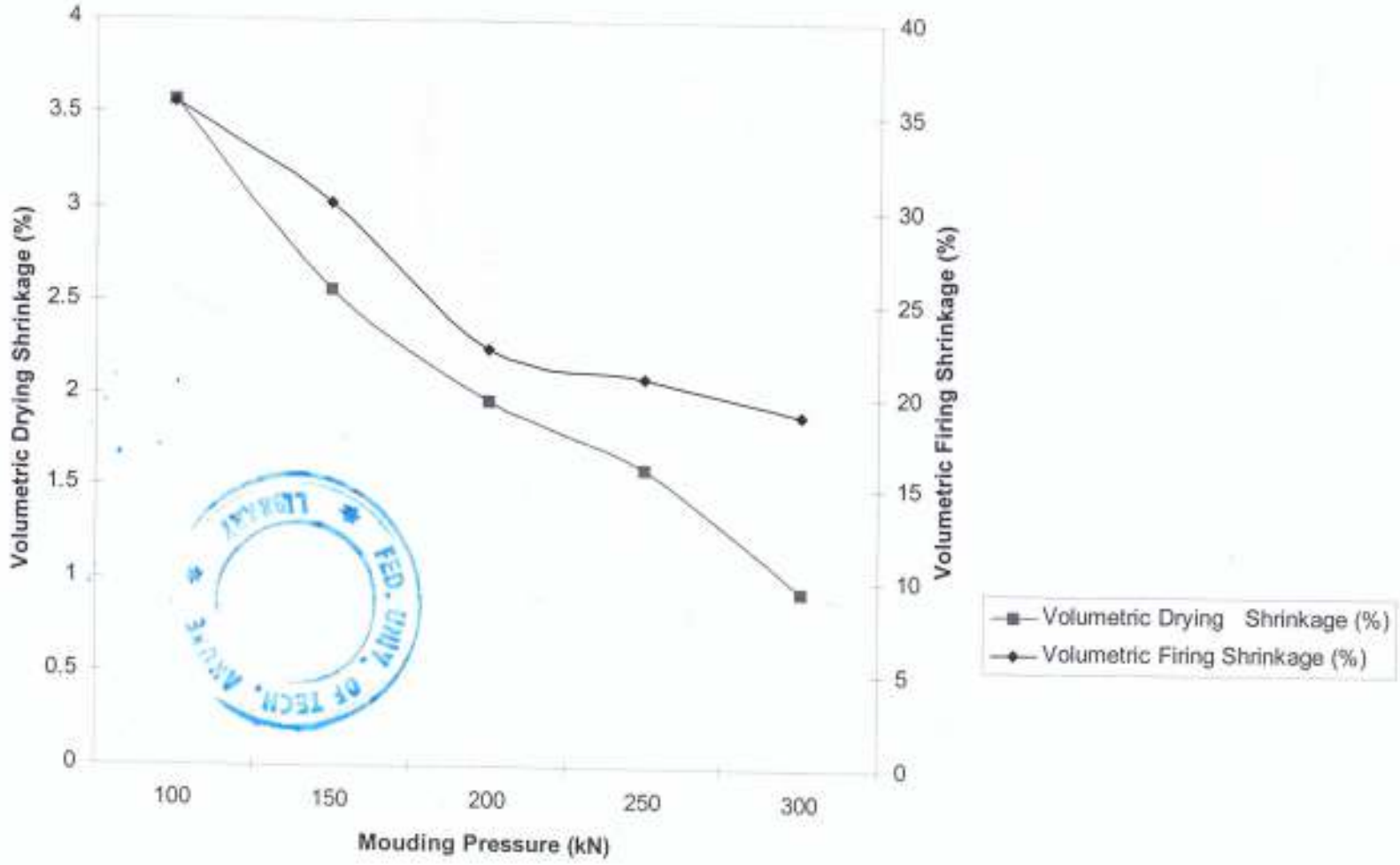


Fig. 4.2: The Effect of Moulding Pressure on the Volumetric Drying and Volumetric Firing Shrinkage of Ijapo Clay with 5% Bentonite as Binder

4.1.2 Effect of Grog Addition on the Properties of Ijapo Clay

The effect of grog addition on the physical properties of Ijapo-clay was studied. Addition of grog is vital in brick making, especially in the reduction of firing shrinkage. Experiments were conducted on several ratios of grog: clay with 5% bentonite as binder. Grog was added in steps of 5% for the preparation of samples. Fig. 4.3 presents the effect of grog addition on the apparent porosity of Ijapo Clay. It was observed that the apparent porosity increases slightly with increase in grog addition.

Experiments carried out on the determination of the effect of Grog addition on the cold compression strength is also reported in Fig. 4.3. Studies revealed that the cold compression strength of the bricks reduces with an increase in grog addition. The reduction is as a result of the increase in apparent porosity of the bricks with increasing grog addition.

Fig. 4.4 presents the effect of grog addition on the linear and Volumetric Firing shrinkage of Ijapo clay. It was discovered that both the linear firing shrinkage and the volumetric firing shrinkage of the bricks reduces with an increase in grog:clay ratio. The higher the grog content of the mixture, the lesser the shrinkage (Chesti, 1986). Low firing shrinkage is needed in refractory bricks production. This is one of the reasons for grog addition.

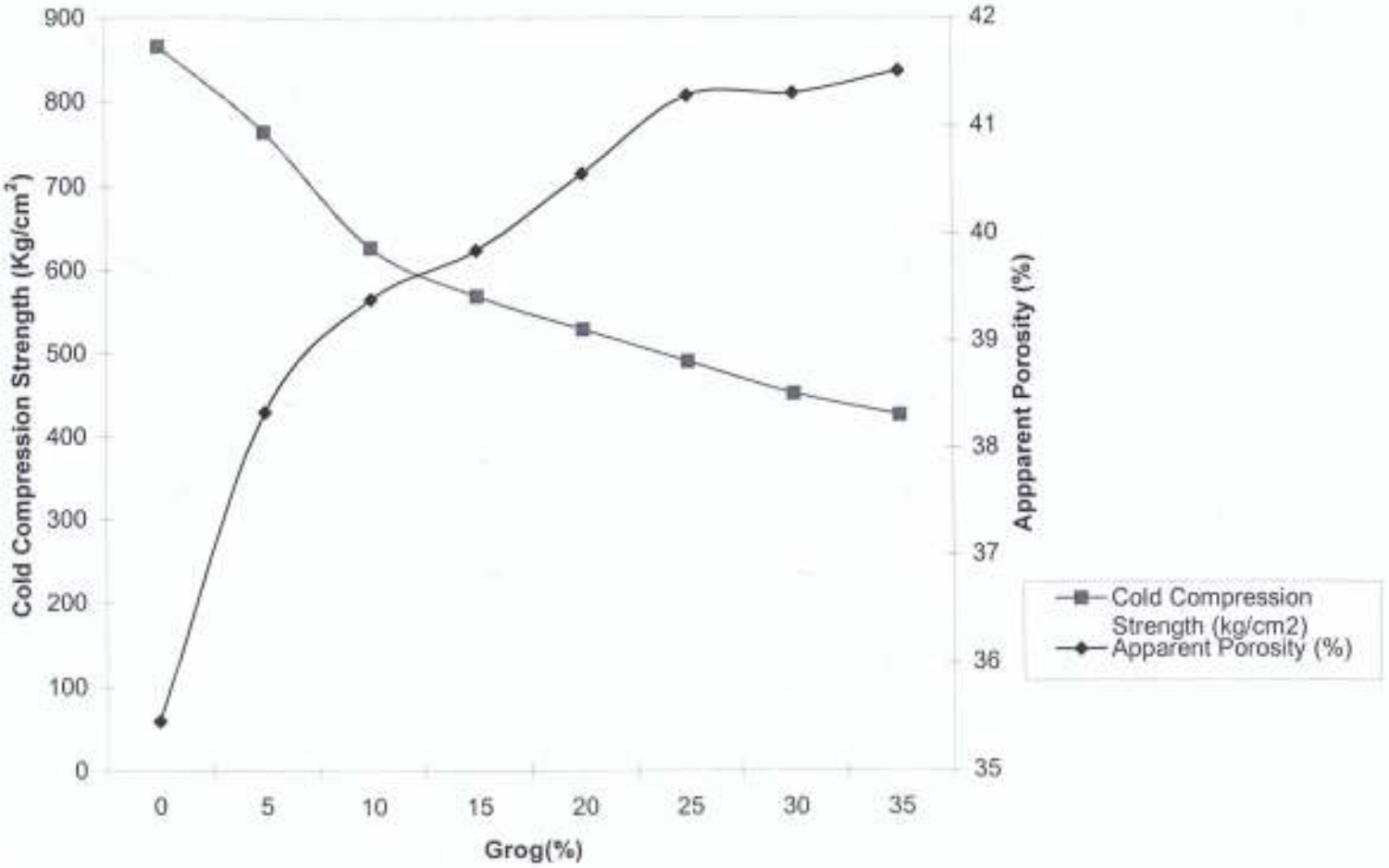


Fig. 4.3: The Effect of Grog Addition on the Apparent Porosity and Cold Compression Strength of Ijapo Clay

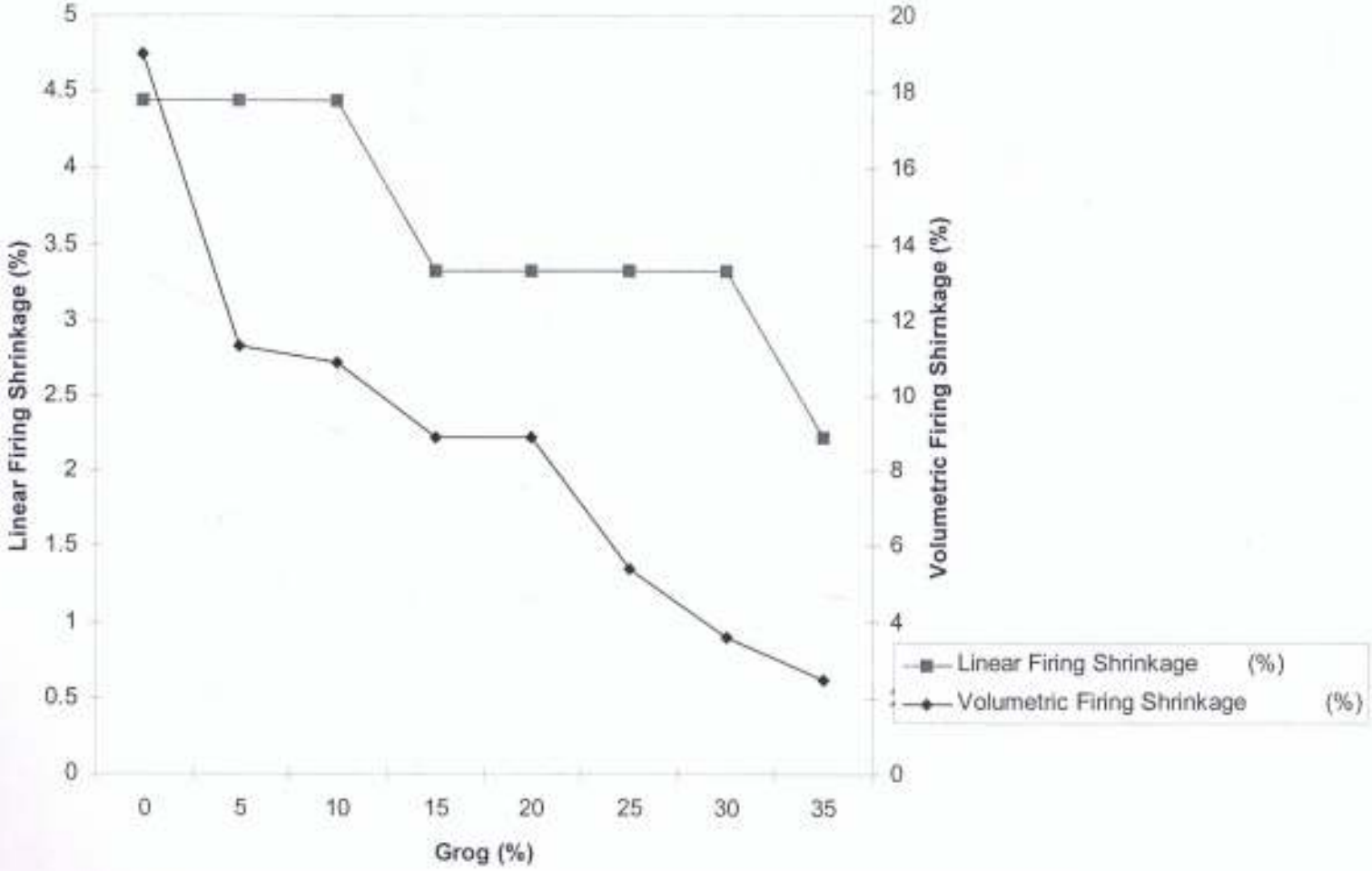


Fig. 4.4: The Effect of Grog Addition on the Linear and Volumetric Firing Shrinkage of Ijapo Clay

4.1.3 The Effect of Sintering Temperature on the Physical and Mechanical Properties of Clay-Grog-Bentonite System

Studies were undertaken on the effect of sintering temperature on the properties of clay-grog-bentonite system. The 20:80 grog:clay mix was used for this investigation. Sintering temperature ranged between 1200°C and 1500°C. From Fig. 4.5, as the sintering temperature increases, the apparent porosity decreases. This is due to the fact that increase in sintering temperature leads to further densification of the materials and consequently, more of the open pores became closed leading to a reduction in the apparent porosity of the samples (Lee and Rainforth, 1994).

The effect of sintering temperature on the cold compression strength of clay-grog-bentonite system is also presented in Fig. 4.5. It was observed that the cold compression strength increases with increase in temperature. This occurred because of the densification of the bricks, which increases with temperature. More pores, which acted as stress raisers became closed. The fact that there is no reduction in cold compression strength even at 1500°C signifies that the refractoriness of the sample is significantly high since glass formation is still very minimal.

Figs. 4.6 present the effect of sintering temperature on the linear firing shrinkage and the volumetric Firing shrinkage of the clay–grog–bentonite system respectively. It was observed that there is an increase in shrinkage of the bricks with increasing temperature. Densification of the samples led to the shrinkage observed with increasing temperature.

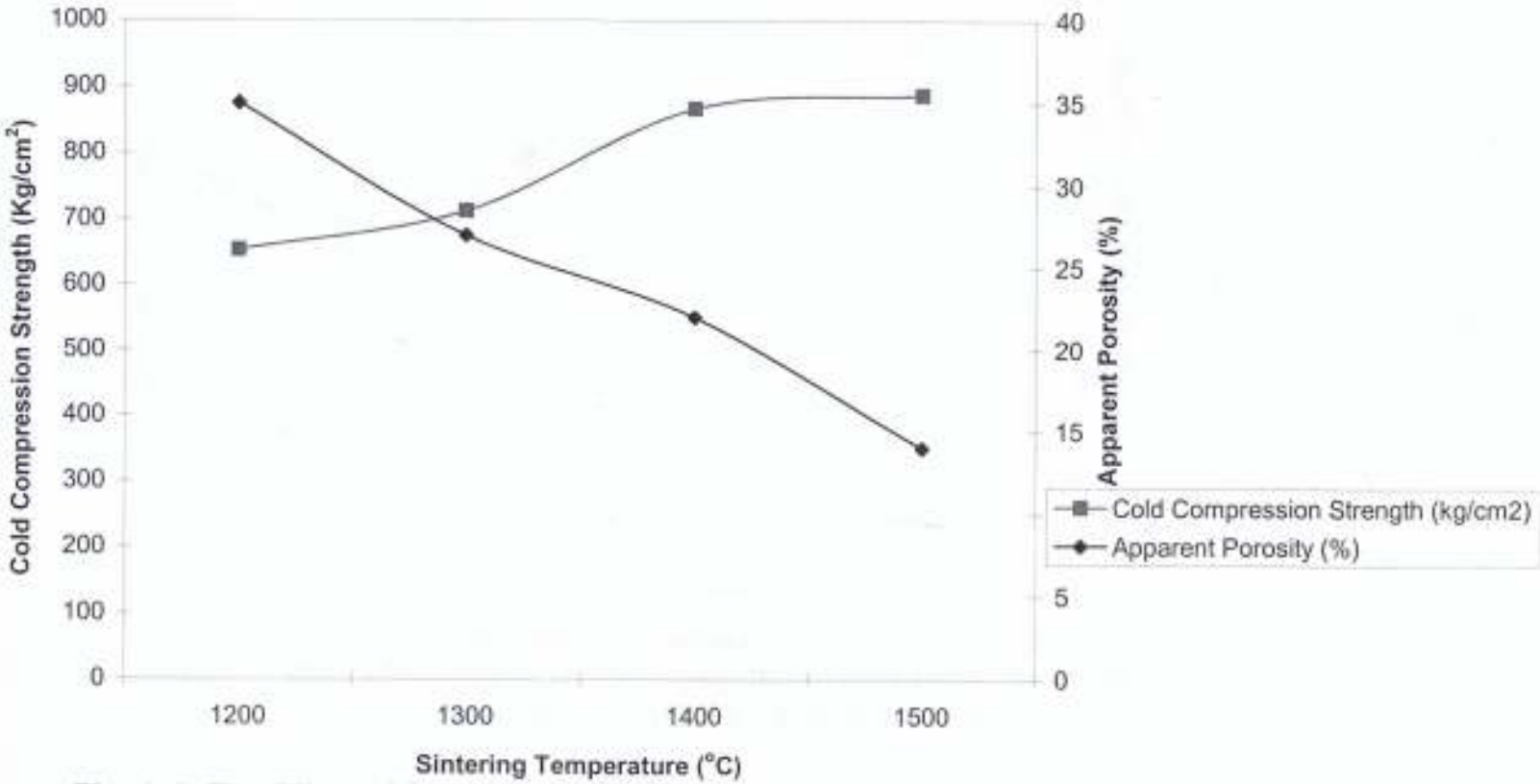


Fig. 4. 5: The Effect of Sintering Temperature on The Apparent Porosity and Cold Compression Strength of Clay-Grog-Bentonite System

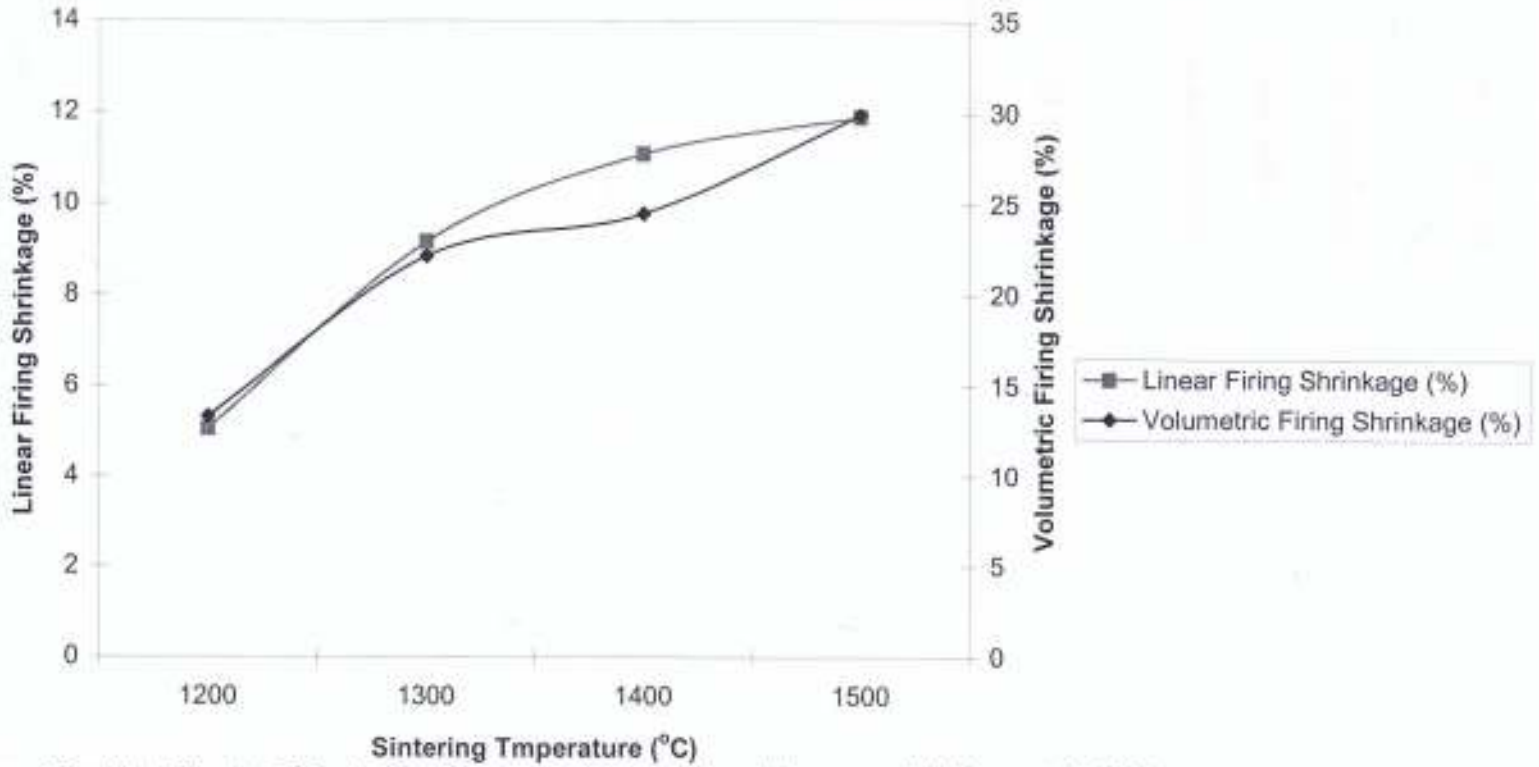


Fig. 4.6: TheEffect of Sintering Temperature on the Linear and Volumetric Firing Shrinkage of Clay-Grog-Bentonite System

4.1.4 Thermal Shock Resistance and Refractoriness

All samples withstood more that 30 cycles during the thermal shock resistance test. This signifies an excellent behaviour to temperature fluctuations when in use. The refractoriness of all samples is greater than 1500°C (the maximum obtainable temperature for the furnace used.). This signifies that the bricks could be used as service bricks for non-ferrous and cast-iron foundries.

4.2. COST JUSTIFICATION

Existing System

Brick dimension is 232 x 116 x 77mm

Internal diameter

500 – 2(77+5)=500-164

= 336mm

Number of bricks around the circumference

$\pi D = \pi \times 336 = 1056mm$

$= \frac{1056mm}{116mm} = 9$ bricks

No. of bricks along the length of the shell

$= \frac{900mm}{232mm} \equiv 3.87 \simeq 4$ bricks

Total number of bricks required for the cylindrical part of the shell

$= 9 \times 4$

= 36 bricks

For the conical sections:

Bricks outlay at the base formed the basis for the no. of bricks used.

Number of bricks around the big circumference ≡ 9 bricks. Since there is only a single row, therefore Total number of bricks required to line a cone = 9 x 1

= 9 bricks

∴ For the two conical sections of the shell, the total number of bricks = 9 x 2 = 18 bricks

Hence, total no of bricks required is 36 + 18 = 54 bricks

New System

Brick dimension is 100 x 50 x 15mm

∴ Number of molded bricks (in experiment) to be used to line a 100kg rotary furnace is

$$= \frac{\text{Large sized brick volume x total member of bricks normally used}}{\text{Small sized brick volume}}$$

$$= \frac{232 \times 116 \times 77 \times 54 mm^3}{100 \times 50 \times 15 mm^3}$$

= 1492 bricks

Joining with fire cement will reduce the number of bricks required in order to keep the thickness of the lining constant.

Volume of fire cement to be wrapped round the brick

$= 2(5x15x100) + 2(5x15x50) + (100x50x5) + 4(5x5x20) + 2(5x50) + 2(5x5x100)$

$= \underline{57000mm^3}$

Equivalent to

$\frac{57000}{100x50x15} = 0.76$ bricks

That is around every small brick, 0.76 brick volume of fire cement is wrapped round it.

Meaning, Brick: Fire cement = 1 : 0.76

Therefore, the number of bricks required is equal

$\frac{1}{1.76} \times 1492$ bricks

$= 847.73$

$\approx \underline{850}$ bricks

Using the volumetric shrinkage at 1200°C, which is 8.87%

Bentonite + Mix (grog : Kaolin = 20 : 80)

2.5kg + 50kg

$= \underline{52.5kg}$

Since mass α volume (from DV = M)

Approximate

$\therefore$ Shrinkage

$= \underline{8.87} \times 52.5$

100

= 4.657kg

Total weight of mix in form of brick left from a 50kg mix = 47.843kg

Weight of 1 small molded brick (100x50x15)

= 45.5g

= 0.0455kg

Cost of Bentonite

25kg costs ₦2,500

Cost of 2.5kg = $\frac{N2500}{25} \times 2.5$

Bentonite = ₦ 250

Cost of grog = cost of 20% processed on 50kg basis + approximate cost of grog

(firing at 1300°C, time for natural cooling to room temperature, crushing, milling & sieving)

= $\frac{20}{100} \times 1200 + 1600$

= ₦ 240 + N1600

= ₦ 1840

Total cost based on 50kg output:

Is ₦ (250 + 960 + 1840)

= ₦ 3,050

Therefore,

Cost of one brick of dimension 100x50x15

= ₦ 3.050 x 0.0455kg

50kg

= ₦2.78 = ₦ 3.00

Lining of 50kg rotary furnace (Existing System)

Cost of Brick:

54 bricks of size 232x116x77mm are used @ N350 each

∴ cost of brick = ₦ 18,900

Cost of Fire Cement:

250kg of fire cement is utilized

25kg of fire cement = ₦6,000

∴ 200kg fire cement = 6,000 x 250
25
= ₦60,000

Cost of setting;

(Based on handling time, time of curing of layers before rolling, time of gradual heating, time of firing) with 2 foundry men (1 supervisor + 1 technician)

= 4 days @ ₦ (18,000 + 12,000) = ₦30,000 for 30 days

∴ cost of setting = $\frac{₦30,000}{30} \times 4$

= ₦4,000

Hence,

Total Cost of Lining a 50kg furnace with brick size 232x116x77 is

= ₦ (18,900+60,000+4,000)

= ₦82,900

Lining of 50kg rotary furnace with brick 100x50x15mm (New System)

Cost of brick:

850 bricks required @ ₦3.00

cost of brick = 850 x 3

= ₦2,550

Cost of Fire Cement

200kg of fire cement required

25kg of fire cement = ₦6,000

∴ 200kg of fire cement = $\frac{6,000 \times 200}{25}$

= ₦ 48,000

Cost of setting:

(Based on handling time, time of curing of layer before rolling, time of gradual heating

time of firing with 2 foundry men (1 superior + 1 technician)

= 5 days @ ₦30,000 for 30 days

$\therefore$ Cost of setting $= \frac{₦30,000 \times 5}{30}$

$= ₦5,000$

Hence,

Total cost of Lining a 50kg furnace with brick size

100x50x15mm is

= ₦ (10,250 + 40,000 + 5,000)

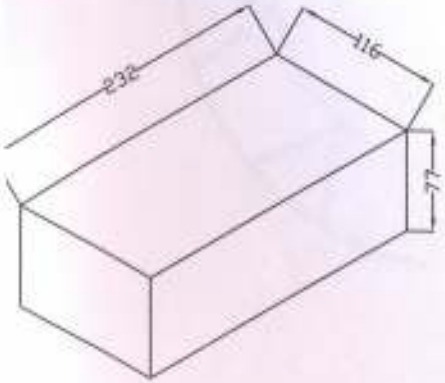
= ₦ 55,550

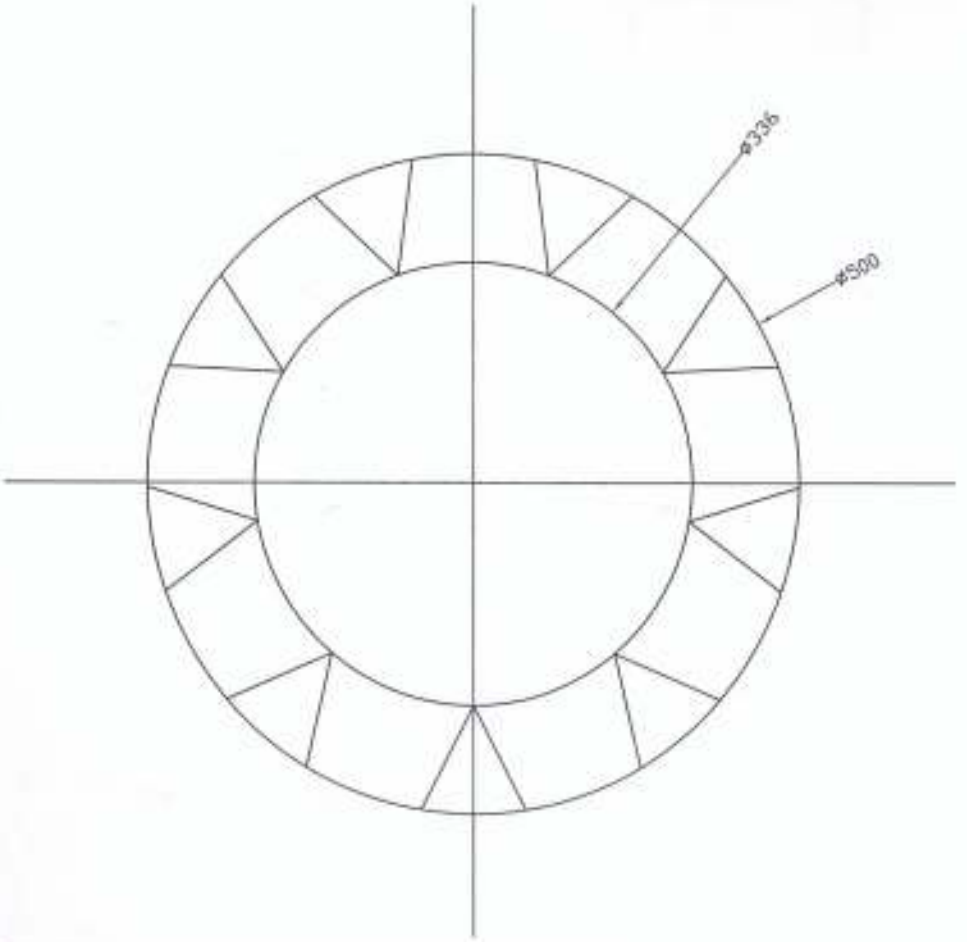
Difference in cost of lining

= ₦ (82,900 – 55,550)

= ₦27,350

It is envisaged that cost of lining using refractory brick made for Ijapo clay is approximately 67% present cost using imported refractory bricks. And this may go as low as 40% - 50% when mass production methods is employed.





All dimensions in mm

Fig. 4.7: Cylindrical Section of Rotary Furnace Lining

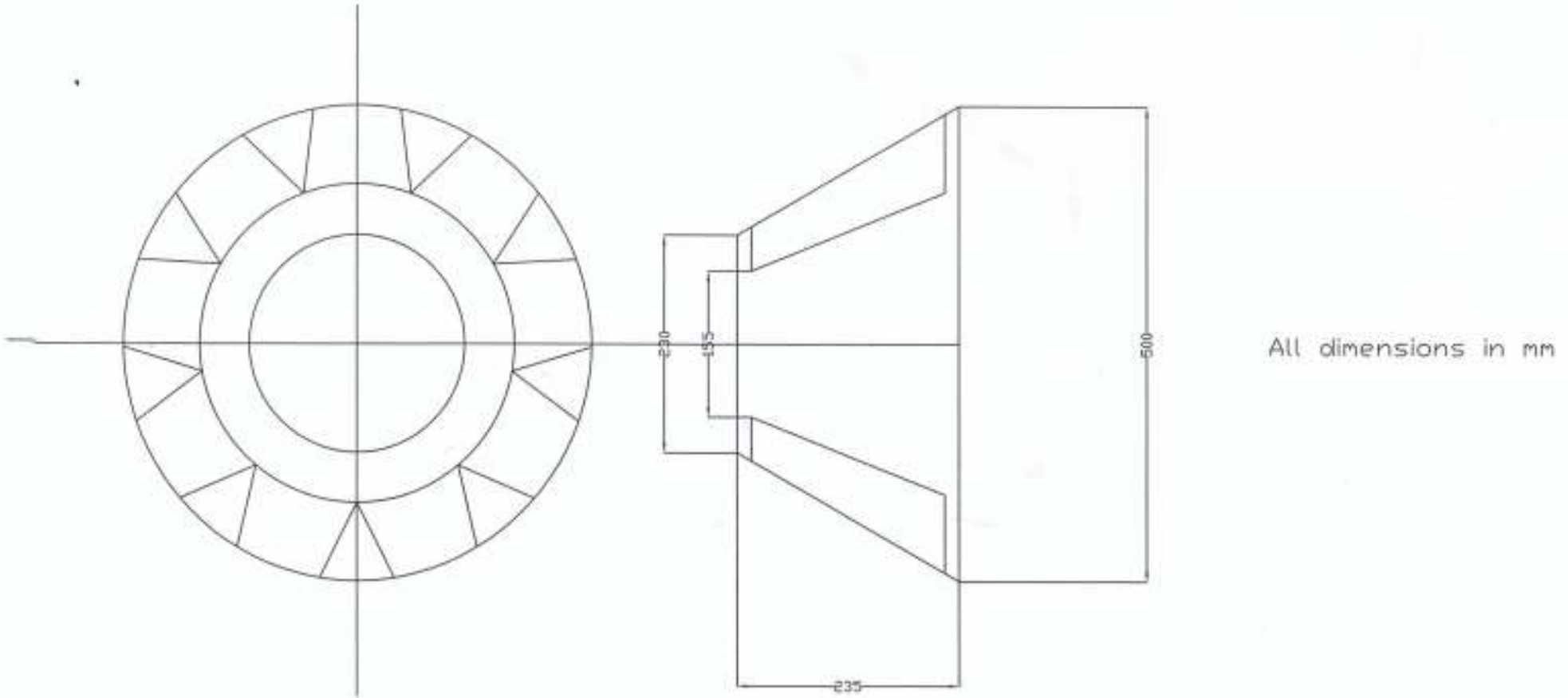


Fig. 4.8: Conical Section of the RotaryFurnace Lining

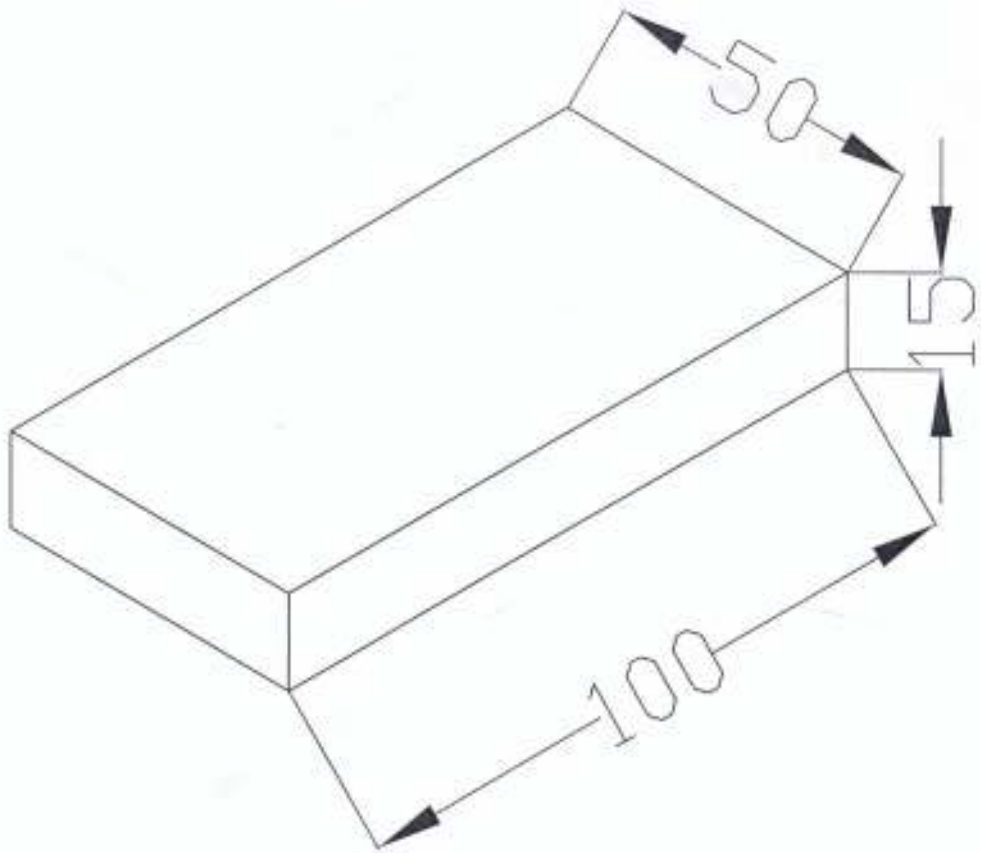


Fig 4.9: New Brick Dimension

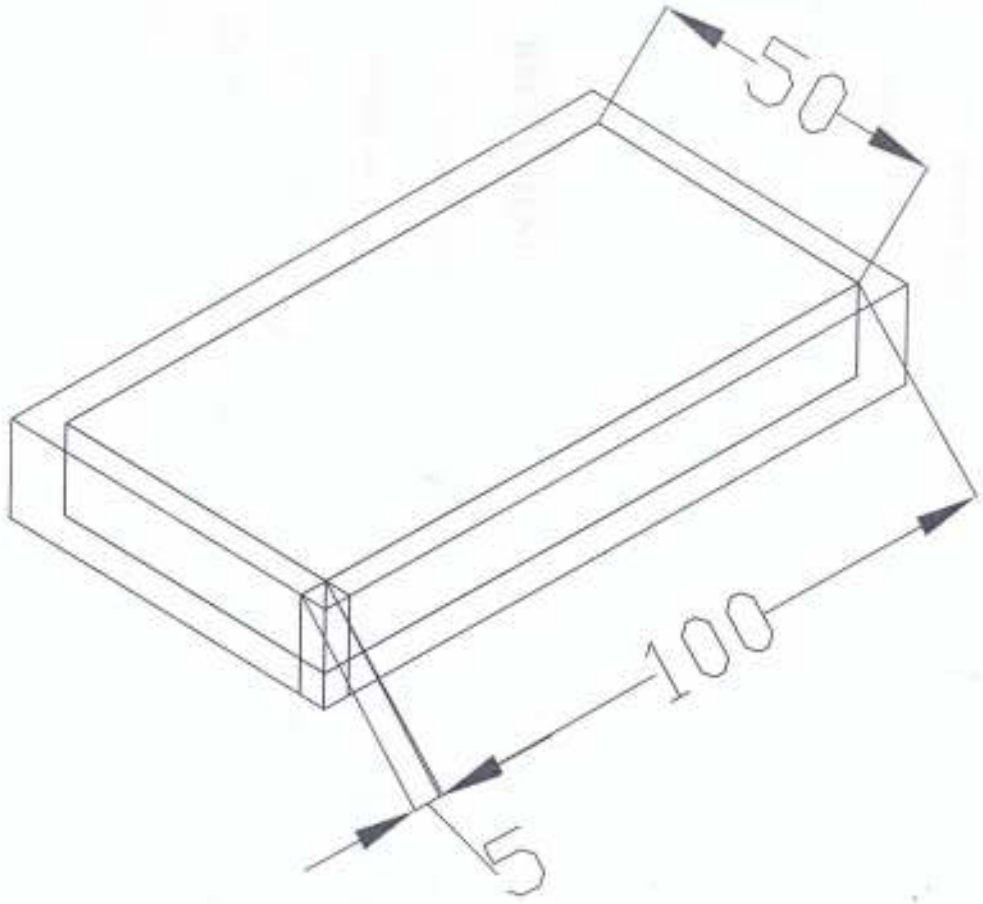


Fig. 4.10: The New Brick System for Lining

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The research work has shown that the 80:20:5 Ijapo-clay: grog:bentonite ratio mixed with 18%w/w water is suitable for the production of aluminosilicate refractory bricks for the lining of metal melting furnaces. A refractoriness >1500°C obtained from the samples tested make this composition suitable for both ferrous and non-ferrous foundries. This makes the melting of such metals as Aluminium, Brass, and Cast-Iron possible. This may even be applicable to steel melting since the actual refractoriness could not be ascertained due to lack of facilities. The cost comparison of lining furnaces with bricks produced using existing system and the new system proved that the new system cost 67% of the existing system. There is therefore a savings of 33% in terms of cost. This is as a result of the local content.

It could therefore be concluded that this refractory brick can serve as a viable alternative to imported bricks for the same application.

5.2 RECOMMENDATIONS

It is hereby recommended that more work should be carried out on other clay deposits across the country so that the dream of Nigeria as a potential industrial giant in the foundry industry can be realized. Facilities for ascertaining the refractoriness of materials should be provided so that work in this area could be made easier and results obtained.

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