EXPLORATION OF THE POTENTIALS OF GRANITE SAWING WASTE IN THE DEVELOPMENT OF CERAMIC BODIES

BY

ALKALI CEPHAS VERSHIMA

DEPARTMENT OF INDUSTRIAL DESIGN
AHMADU BELLO UNIVERSITY, ZARIA, NIGERIA.

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BY

ALKALI, CEPHAS VERSHIMA,
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DEPARTMENT OF INDUSTRIAL DESIGN
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OCTOBER, 2014.

DECLARATION

I, Vershima Cephas Alkali, hereby declare that the work in this dissertation entitled "Exploration of the Potential of Granite Sawing Waste in the Development of Ceramic Bodies has been conducted by me in the Department of Industrial Design Ahmadu Bello University Zaria. In the course of this sturdy, some research works were conducted at Defence Industries Corporation (DIC), Kaduna. Industrial Development Centre, (IDC) Zaria. The information derived from literature has been duly acknowledged in the texts and in the list of references provided. No part of this dissertation was previously presented for another degree or diploma at any University.

Alkali Cephas Vershima	**Signature**	**Date**

Certification

This Thesis entitled **Exploration of the Potentials of Granite Sawing Waste in the Development of Ceramic Bodies** by Alkali Cephas Vershima meets the regulations governing the award of the degree of Doctor of Philosophy in Industrial Design of Ahmadu Bello University Zaria. It has this day been approved for its contribution to knowledge and literary presentation.

..... Date.....

Professor A.M. Ahuwan
Chairman Supervisory Committee
Department of Industrial Design
Ahmadu Bello University, Zaria.

..... Date.....

Dr A. D. Garkida
Member Supervisory Committee
Department of Industrial Design
Ahmadu Bello University, Zaria.

..... Date.....

Professor U.A. Sullayman
Member Supervisory Committee
Department of Industrial Design
Ahmadu Bello University, Zaria.

..... Date.....

Dr S. Maiwada
Head of department
Department of Industrial Design
Ahmadu Bello University, Zaria.

..... Date.....

Professor A.Z. Hassan
Dean School of Postgraduate Studies
Ahmadu Bello University,Zaria.

DEDICATION

This research work is dedicated to my wife and two children. Tomna Israel and Msuugh Jemima and to the system that provided this platform for this research endeavour and academic attainment namely, Department of Industrial Design, Ahmadu Bello University Zaria.

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DEFINITION OF SPECIAL TERMS

Flux: Lowest melting compound. It combines easily with Silicates and thereby help in melting alumina and silicate compounds.

Beneficiation: The process of transforming raw materials to a usable stage by means of processing.

Paraluminous: Is a type of granite rock in which feldspar and quartz is the dominant mineral usually light in colour.

Metaluminous: Is a type of granite rock in which magnesium carbonate and feldspar dominate the minerals and its composition. It is usually dark in colour.

Mafic: Is a classification of granite rock where feldspar and magnesium are dominant materials.

Biotite: Is a description of a granite rock which is classified under the mafic family.

Felsic rock: Is a classification of granite rock which has Feldspar and quartz as dominant materials.

Cordierite: Is a kind of granite rock which falls under the family of the felsic rocks.

Biotite-Hornblend: Is granite that comprises of both biotite and hornblend type of rock.

Sintering: The bonding and fusion of various ceramic materials by means of heating or firing.

Thermal stress: It is a test to determine the ability of a refractory material to withstand heat and cold by subjecting it to rapid and widespread changes in temperature.

Waste: A by-product of parent material.

Pollution: An art of destroying the purity of the environment.

Coning and Quartering: A procedure recommended for mixing samples, in which a sample is mixed into cone-like heaps on a clean or cemented surface and split into quarter dimensions and each mixed into a fresh cone until the required mixture needed for a composition is achieved.

Body: Clay for a special purpose which is created by blending different clays or by adding to clays other minerals such as granite, feldspar and flints.

Tempering: The inclusion of other materials into natural clays for a desired effect.

ABSTRACT

The granite industry generates a large amount wastes in various grain sizes which lie in heaps in several quarry sites. This material during rainy season constitutes an unhealthy mud causing serious environmental pollution. Despite the potential economic and technological advantages these wastes offer, little is done to utilize them for other industrial applications apart from its use in the building industry. The use of granite waste as alternative material in the production of ceramics has been a viable option by many researchers in other parts of the world. Granite waste has been re-absorbed as secondary raw material in the production of bricks, wall tiles, floor tiles and roofing sheets. This is in response to the global mobilization programme that reveals the strategic importance of waste materials as important source of raw materials for the production of tangible domestic and industrial products. The aim of this study is to adopt granite sawing waste and incorporate it into natural clay to produce a ceramic body that could be used in producing various decorative objects. This granite waste would serve as a tempering material in the formulation of a clay body that fuse at lower temperatures and produce other effects that may create a differential feature and save cost. This process involved the collection of granite sawing waste from three quarry sites across Kaduna state and combining it by studio experiment with primary and secondary clay for the formulation of different body compositions. This effort was successfully carried out and test bars and sample wares were produced and fired between 900^0c-1200^0c. These were subjected to various tests to establish their chemical content, physical and mechanical properties required for a workable body. Result showed that granite combined effectively with ball clay and kaolin to produce four bodies that met the requirement for the production of ceramic wares through the casting method. The bodies obtained shrinkage values of 5-7% and water absorption rate of between 3-22%. They sintered and fused at 1200^0c and were able to absorb glaze and glaze fusion without any visible defect. This showed that granite can compliment clay in the formulation of bodies for various purposes.

CHAPTER ONE

1.0 Introduction

1.1 Background of the Study

For several decades, attempts have been made towards the preservation and utilization of industrial wastes or waste materials. This is because it is believed that they constitute an important source of alternative raw materials having the same use as its primary raw materials, although they are often referred to as secondary raw materials.

Massive development projects worldwide are creating a critical shortage of raw materials and this challenge is equally being matched with a corresponding effort aimed at recycling materials as an important secondary source of supply. There is hardly a manufacturing industry that does not produce some waste materials in the course of its operation. Often times, these wastes constitute a serious environmental problem of monumental proportion because of the erroneous concept that such wastes are no longer useful. There is therefore urgent need to conceive ways of converting such wastes to tangible secondary materials for the production of useful products.

In spite of the fact that granite industry in Nigeria generates a large amount of wastes in form of fine grain size powder which during rainy seasons transform into mud leading to some environmental damage, little attention is given to its maximum utilization for other industrial applications apart from its widespread use in the building industry. The use of granite wastes as alternative raw material in ceramics is quite a viable option that can contribute in not only diversifying the offer of raw materials but can save cost, provide alternative raw materials and new aesthetic advantage. The chemical composition of granite which consists of SiO_2 Al_2O_3 F_2O_3 and CaO, makes it

a suitable material for use in other applications in the ceramic industry apart from its present use as a glaze material.

Ceramic bodies and glaze recipes are two means by which ceramists express themselves through their products. The search for better and dependable bodies has been a continuous one. The term clay often refers to synthetic blends of various mineral compositions. Many types of clay naturally do not possess all the desired properties for any given purpose. It is the combination of several sorts that contribute in making a workable body. The following properties combine to form a workable body. These are, handling properties, and fired properties. Granite by its very nature does not possess all the above properties, hence the need to combine by studio experimentation several other materials to form a workable body. According to Conrad (1980) the reason for addition of some clay bodies is the offer of an inexpensive body constituent while in some, it is that they offer special physical attributes.

1.2 Statement of the Problem

Due to the numerous construction works going on particularly the construction of roads and other projects, a lot of granite waste is being generated from the quarrying of granite rocks. Much of the wastes lie in heaps across the length and breadth of this country causing serious degradation to soils and the environment. Alkali, Ahuwan, Garkida.(2006)

The construction industry seems to one the only industry involved in the absorption of these waste to produce concrete blocks and other products. The use of granite waste as alternative raw material in ceramic industry is yet to attract the attention of most researchers apart from it's seldom use as a fluxing agent in the production of glazes. While efforts have been made in several countries to recycle

granite waste in the ceramic industry to produce a variety of products including bricks, floor tiles and roofing tiles, little seems to have been done to this effect in Nigeria. The problem of this research therefore, is to explore the potentials of granite waste in developing ceramic bodies for the production of decorative and other functional wares.

1.3 Aim and Objectives of the Study

The aim of this study is to utilize granite waste generated by the quarry industry for the development of ceramic bodies that can be cost effective and yet functional with some aesthetic appeals

The objectives of the study are to:

1. Identify the potentials of granite waste as additional raw material in the production of ceramic wares.
2. Carry out the characterization and property test of granite waste in order to determine its suitability in body formulation and production.
3. Find other ways of rechanneling wastes produced from granite sawing to encourage diversification in the re- use of this raw material thereby reducing the level of environmental pollution.
4. Produce samples of functional and aesthetic ceramics using waste from granite sawing.
5. Carry out tests on the sample wares.
6. Develop glaze batches that will match the ceramic body formulated.
7. To establish the optimal formulation that has the best performance.

1.4 Significance of the Study

Dijkema(2000),stated that, nowadays, industries are searching for alternative raw materials that are less costly and recyclable so as to minimize waste as well as conserve the primary raw materials. This underscores the importance of these wastes as secondary materials to the economy of several nations.

The current cost of production of ceramics has been a very discouraging factor to most operators in this industry. This observation is equally supported by Ahuwan (1997).The cost comes primarily from beneficiation of raw materials to the level where they become functional means of production. The use of granite waste will reduce the cost involved in the processing of these raw materials.

Importantly to this, it is expected that granite being majorly a medium range fluxing agent, may not withstand high temperatures that are required in the firing of other clay bodies. This by implication means that the cost involved in sintering granite based bodies will be less compared with other bodies.

Lastly, ornamented stone cutting rejects such as marble and granite are inert and dangerous and are becoming a worry to industry owners and environmentalist. A large amount of these wastes are washed by erosion and carried by winds unto crops and plants thereby becoming an unhealthy mud to the environment and crops. These granite rejects can be used in improving the sinterability of clay bodies as well as serve as a tempering agent in ceramics. By this, further degradation of the environment by this waste material will be minimized.

1.5 Basic Assumption

The successful completion of the research conducted is based on the following assumptions:

1. That the granite wastes obtained from quarry sites within Kaduna State will combine effectively with natural clay in developing clay bodies suitable for casting.
2. The properties necessary for a functional body would be derived from the experiment.
3. The chemical content of materials adopted for the study are compatible in nature.
4. The sintering obtained by firing will be enough to impart strength and durability on the body.
5. The body obtained will meet the required absorption levels suitable for glaze adhesion and fusion.
6. The body formed will fire at lesser temperature, thus conserving fuel, and human energy.
7. A good body that can be employed for ceramic production can be achieved.

1.6 Research Questions

To facilitate the achievement of the objectives set in this study, the following research questions were formulated:

1. What reaction can be generated by combining granite sawing dust with clay body?
2. Would all required properties necessary for a functional casting clay body be derived from the formulated bodies?

3. What would be the possible outcome of the chemical and physical tests carried out on the materials required for the formulation of these bodies?
4. When these bodies are subjected to heat treatment, will they sinter at the required temperature?
5. Since granite is a medium range temperature flux, can it withstand high temperature required for stone ware?
6. Will the body meet the required absorption level or porosity required for glaze adhesion?
7. Can a good ceramic body that can be employed for ceramic production be achieved?

1.7 The scope of the Study

The study specifically concerns itself with the use of granite waste in the production of ceramics and the determination of the physical properties inherent in granite, their suitability for body formulation and production in ceramics. Samples of granite waste are taken from three granite sawing mills located at different locations across Kaduna State. These are Sabon Gari, Igabi and Kajuru Local Government areas.

1.8 Delimitation of the Study

The study is delimited to granite waste obtained from sawing mills in three local government areas which are: - Sabon Gari, Igabi and Kajuru in Kaduna State. The varied nature and chemical variation of granite due to their location and geological process of formation is not the central focus of this research.

Granite may possess limitless potentials in solving structural problems in ceramics. However, the body to be developed is strictly to be used for the production of

decorative and aesthetic ceramics. This study is therefore not concerned with the chemical analysis that will determine their safety for table and kitchen use.

1.9 Limitation of the Study

Lack of specialized equipment such as scanning electronic microscopy (S.E.M) to carry out other scientific investigations to determine other technical and engineering properties of granite based bodies and glaze as suggested by Xavier, Saboya, Maia and Aleandre, (2011) is the major limitation to the study. For this reason, this study is limited to the chemical analysis and characterization that established the functional requirements in the production of ceramics.

CHAPTER TWO

2.0 Review of Related Literature

2.1 Introduction

There is a large scale global mobilization programme geared towards discovering the strategic importance of waste materials as a vital secondary source of raw materials supply for industries. Consequent to this is the development of highly technical processes that will facilitate the preparation and utilization of these wastes. The use of granite wastes from sawing mills as an additional raw material in the ceramic industry is generating a lot of interest from among ceramic researchers and industry operators as indicated in the body of the literature of this research. The review will therefore focus on:

1. The nature, potentials and uses of granite as a primary and secondary raw material in the construction industry of which ceramics is one.
2. Review of literature on past works that deals with the conservation and utilization of solid wastes as a global phenomenon.
3. Environmental issues associated with waste disposal
4. The previous efforts that resulted in developing ceramic bodies for varied applications in ceramics
5. Process involved in material formulation, production and finishing.

2.2 The Nature and Uses of Granite Rocks

Pitcher (1993) says that granite is one of the naturally occurring members of the rock family and is part of a variety of quartz-bearing igneous rocks. According to him, granite originated from the convergence of the magmas of quartzite rocks and three feldspars, potash, soda and lime feldspars.

It could as well be argued that any attempt to categorize the granite family on a natural basis is doomed to failure given the generative processes involved in their formation. However, sources from available literature indicates that granite rocks are basically of two kinds whose compositional gap is hardly apparent at some point and in some other, very apparent. These are paraluminous granite and metaluminous granite types. The paraluminous type consists of biotite granite bearing abundant corderite while the metaluminous granite bears sphere-bearing biotite-hornblende or grandiorites. The differences reflect the high alumina content relative to alkali and calcium in the paraluminous and the converse in the metaluminous granite. Below in Table 2.1is the summary of the distinctive features of the paraluminous and metaluminous granites rock.

Table 2.1: Classification of granite

Metaluminous granite	**Paraluminous granite**
Horn-blende, common and more abundant than biotite in mafic samples. Has relatively high Na_2O, Molecular Al_2O_3 ($Na_2O + K_2O$) Has broad spectrum of composition from mafic to felsic. Has a mafic hornblende-bearing enclave.	Biotite and muscovite predominate. No hornblende, some cordierite alumino silicates and monazite. Has relative low Na_2O, Molecular Al_2O_3 ($Na_2O + K_2O + CaO$). Has a narrow range of more felsic rocks. Has a sedimentary enclave.

Source: Pitcher (1993).

Rania, Salah and Safiran, (2001) described the granite wastes from sawing industries as mud, basically composed of SiO_2, Al_2O_3, F_2O_3 and CaO. The chemical composition and particle size distribution makes it suitable for a variety of applications. Until recently, granite rocks were known for their widespread use in the building and

construction of roads and houses. Up till now, the construction industry remains the most indicated technology activity sector that uses the granite sawing mills in generating raw materials for construction purposes.

The use of granite in the ceramic industry until now never attracted much attention despite its physical attributes that makes it a suitable material in a wide range of applications in ceramics. Studio experiments by Alkali (1995) shows that granite wastes are a cheap source of glaze flux and have the additional advantage of being non-soluble. Torres (2003) however observed that because of the presence of Al_2O_3 and $Si0_2$ in granite, it cannot be considered for low temperature flux. However, the fluxing action could be increased by the fineness of its particle size. Conrad (1980) further observed that granite rock because of its similarity in characteristics with feldspar could serve as alternative material to feldspar in the formulation of clay bodies and ceramic glazes.

According to Nelson (1964) there are three principal components in a glaze. One of these is silica $Si0_2$ which gives the glaze its glassy, transparent quality. The second is alumina AI_20_3 a refractory element, which contributes toughness and abrasion resistance to glaze. Since neither of these oxides will melt at temperatures lower than 3100f, the third component is required which is the flux such as sodium, to lower the melting point, and combine with alumina and silica to form a hard glossy coating on a ceramic body. Since all these characteristics are found in granite rocks, it could and has been considered for use in the composition of glaze and ceramic bodies for various applications.

Throughout the world, the granite mining and processing industry is becoming one of the most promising industries with a mean growth in the world production of approximately 6% per year in the last 10 years. The international trading is

approximately 6 billion US Dollars per year and around 13 billion US Dollars taking into account tools, equipments, etc. (Totza, Achar and Vieira, 2000).

Records show that Brazil is one of the biggest world producers of granite either in form of block or processed products. Most of the residues in form of secondary raw materials have been used in the production of stable glassy phases in the glass and glass-ceramic industry. These have been used in overcoming some problems associated with the production of bricks and tiles with granite serving as their major constituents.

Vieira, Monteiro and Pecanna, (2003) revealed that granite raw material has been a major source in the production of red clay ceramic products such as bricks and roof tiles. According to these authors, granite has as major constituents, feldspar, quartz and mica and these are classified as high temperature fluxes and therefore act as glassy phase formers during sintering process, thus helping in improving the sinterability of clay materials. They equally observed that, because these materials have non-plastic character, they play a vital role as plasticity controllers during fabrication in the manufacturing industry.

Vieira, et al; ibid equally observed that one technological alternative to reduce refractoriness and porosity of ceramic materials is to increase the flux content in the bodies. Fluxes are raw materials with a high amount of alkaline oxides, mainly K_2O and Na2O which in reaction with silica and alumina, promote liquid phase formation that facilitates densification. The liquid phase surrounds the solid particles and by surface tension enables the particles to approach closing the porosity. The powder waste from sawing operations of ornamental rocks such as granite has been a potential raw material that could serve as a flux source at medium range temperature and has become a chief material in the production of red ceramics.

Results from the experiments by these researchers showed that granite waste can improve the extrusion process of red bricks as well as optimize their plasticity. This is achieved by tempering the plastic clay with granite waste, thereby reducing its plasticity which hampers easy extrusion. It equally facilitates drying shrinkage. It further decreases the open porosity of the fired bricks. Consequently, the researchers concluded that the addition of granite waste in the formulation of red bricks yielded positive result as this addition did not affect flexural strength of the bricks. These results go on to prove the dependability of these wastes in solving and improving several production problems and efforts in a wide range of ceramics.

Granite has been a chief material in the production of porcelainized stoneware as a flooring material of the ceramic industry. Rincon and Hernandez (2001) described porcelainized stoneware as a compact product, extremely hard and homogenous, generally not fully vitreous in its surface and obtained by fast firing. The final product is characterized by its almost zero porosity, and as a consequence, high density adequate enough to prevent fast wear of tiles used in interiors and exteriors of modern classic buildings.

There are many ceramic bodies that are predominantly kaolinitic in nature and contain a considerable amount of gibbsite. These are responsible for the refractoriness in their firing behaviour. As a consequence, products such as roofing tiles and extruded tiles do not achieve the porosity level required for acceptable level of absorption. One technical procedure to reduce the refractoriness and porosity of these clays is to increase the fluxing agents in the bodies. Granite wastes help in achieving this function.

Available literature also indicates that the ceramic bodies traditionally used for the production of roofing tiles were reformulated by several researchers by the addition of granite wastes from sawing mills in order to produce roof tiles with better

technological properties. Vieira, et al; ibid, observed that, most of the local clays used in the production of roof tiles are predominantly non-kaolinitic in nature and are usually highly associated with high plasticity. Due to the excessive plastic nature of these ceramic bodies, it is common to observe dimensional defects which occur during drying and firing. It was to avoid these problems that clay bodies for the purpose of roofing tiles are reformulated using the granite dusts.

Results from this experiment showed the fluxing capacity of granite sawing residues which is associated with lower porosity after firing. These reformulated bodies brought about practical advantages such as easy drying-operation as well as lower drying and firing linear shrinkages that decrease the risk of dimensional defects.

Granite dust from quarry industries was found useful in the production of concrete bricks. In Egypt, an experiment to this effect was carried out by Rania. et al in (2011), in which concrete bricks were found to have the best application in utilizing granite waste in large quantities to replace conventional sand and aggregate. Traditionally, aggregate in concrete bricks are dolomite which serves as coarse aggregate while sand is used as a fine component. These were effectively replaced by marble and granite wastes. Results showed that marble and granite composition yielded similar mechanical properties in terms of compressive strength, density and absorption properties.

Granite sawing dust is a major material used in the production of green building materials for projects, as noted by Nashville, (2012). Green buildings are designed to reduce the overall impact of the built environment on human health and natural environment. One of the ways suggested to reduce building waste is by recycling waste. Granite wastes have become chief materials in green buildings. Stone fabricators produce a lot of granite waste during the process of making and installing granite

counter tops, cladding walls, back splashes in kitchen, cladding of fire places and oven garden landscaping. This process opens a new market for designers who would want to utilize these wastes for product innovation.

2.3 The Conservation and Utilization of Solid Wastes as a Global Phenomenon

The large scale manufacturing of products to cater for the worlds growing population is creating a critical shortage of various raw materials more than ever before. Thus, the industries are turning a spotlight on the strategic importance of scrap and waste materials as vital secondary source of supply. There is hardly a production sector that does not produce some form of waste material. Whether it is cloth, plastic, wood, aluminium, iron, copper and brass, leather or chemical industries, all these generate great waste which upon treatments is reworked to serve some other useful purposes. The once held view that regarded waste as materials that outlived their usefulness is becoming a thing of the past.

2.4 The Waste Concept

According to Lipsette (1951) the word waste used in this connection is a misnomer since the effective utilization of these so called wastes means that far from being wastes, the various materials in question are put to successful use. It is primarily, the research methods and their resultant application in the various manufacturing fields that have been essential and responsible in translating these wastes to useful materials. Wastes are substances or materials that one would want to urgently dispose off. A substance, however, is a waste only when it is experienced as or labelled as waste. What a producer may consider as unwanted, another may regard it as a potential resource for another project. Waste is a subjective concept or rather a qualification of a

particular material which however changes because what is considered waste today can be a resource in the future. The strategic notion held by Dijkema ibid (2000), is that, a material is qualified as waste only when it is not used to its full potential.

The term recycling and re-use are used interchangeably in the waste management strategy. However, recycling is better defined as use of a waste material as a new material for the manufacture of a new or similar type production. This is specially done to prevent materials from entering the waste stream, as observed by Dino et al (2012)

2.5 Conservation and Utilization

According to Duke, (2009) establishment of a thorough waste management plan generates a lot of advantages both for the quarry industries and fabricators. These include:

1. Improved health and safety. Decreasing the amount of scrapples, airborne particulates, and general trash dumping sites creates a healthier and safer environment for employees.
2. Reduced storage, transport and disposal costs. With less waste to store and transport, the cost of handling waste is minimized. Potential generation of scrap store creates revenue. Sludge and other waste products can be sold on several markets, thus creating a secondary company revenue stream.
3. Increased efficiency: Decreasing the amount of materials lost during quarrying, crushing and cutting processes increase company efficiency and quantity of profitable product. In effect, the company sees a heftier return for every ton of product sold.

4. Enhancement of company reputation. Comprehensive proactive waste management practices can result in not only a socially responsible reputation but in greater community acceptance of the quarry operations.

2.6 Best Practices in Waste Management

The Natural Stone Council (NSC) in its publication of 2009 recommends what it calls best practices in solid waste management. It suggested that each facility develops a waste management plan built on the following:

Produce less waste: Improve production methods to mitigate all types of wastes.

Exploit the value of waste: Implement strategies to reuse, recycle, compose, sell or otherwise prevent waste from being land filled or incinerated. Manage waste properly. Follow regulations for lawful disposal of waste that cannot be given a second life.

The use of industrial waste materials as additives in the manufacturing of ceramic products has been attracting a growing interest from researchers in recent years and this is fast becoming a universal trend. Acchar, Vieira and Sagadaes (2006) noted that the ceramic industry, particularly the sector devoted to the manufacture of building products has been the target for the incorporation of other industrial rejects or wastes. Research in this direction confirmed that waste materials are similar in composition to the natural raw materials used in the ceramic industry. According to Hotza, Acchar and Vieira, (2006) upgrading industrial wastes to alternative ceramic raw materials becomes an interesting development technically and economically.

A classification of wastes by Acchar, ibid, indicates that there are basically three categories of wastes related to ceramic industry. These are fuel wastes (those with high contents of organic or carbon rich substances). The second is fluxing wastes which

improve the ceramic sinterability and other applications and finally, the plastic controlling wastes (those likely to introduce changes in the green body preparation. The granite wastes under investigation are classified under fluxing wastes. Thus the use of granite waste for construction in ceramics will be the focus of this research.

2.7 Waste Management in Nigeria

Nigeria is facing an increase in waste generation and accompanying problems with their disposal and recycling. In the last few decades, extensive building and infrastructure development projects have led to an increase in the generation of construction waste material. The construction industry has substantial impact on the environment and this is as a result of the quality and quantity of waste it generates.

According to Kofoworola (2006) most Nigerian cities do not have an integrated waste management plan and the limitations are obvious ranging from non-involvement of stakeholders in planning and decision making, unskilled staff and lack of professionals as well as absence of long-term waste management strategies. Added to this is weak coordination between authorities and neighbourhood association workers who undertake the primary collection, ignorance, lack of technical resources and basic technology.

A study by Garkida (2006) and Ahuwan,Opoku and Garkida, (2004) reveals that Nigeria produces a lot of glass waste which if not properly controlled and rechanneled for proper use could lead to huge economic losses and serious environmental pollution. This growing concern for the safety of the environment is being demonstrated by continuous agitations for legislation of policies that border on not just effects of the pollution from waste but also how to recover and utilize the wastes.

It is observed that many countries in the world have already taken initiatives to minimize waste generation and improve the management of waste by various legislations in form of directives and regulations. Examples of these are Germany, United Kingdom, Japan and many others. Limbachiya, (2006).observed that, in Taiwan for example, it was legislated that after 2007, disposal of solid waste in land fill sites will not be allowed. In some of these countries, transfer stations for solid wastes have been created as an integral part of waste management system. These are now pushed into compactors and loaded into large containers to various treatment centres for re-use, as stated by Bovea and Powell, (2006). Unfortunately however, Kofoworola, (2006) observed that little of such efforts have yielded any significant result in so many developing countries.

Recent Italian law on solid waste management recommends an increase in material recycling and energy recovery. A correct waste management policy according to them should be based on the principles of sustainable development according to which waste is not simply regarded as something to be discarded but rather a potential resource. Thus Rustici (2006) proposed an integrated waste management plan that makes use of all available technologies. This trend is a universal phenomenon; therefore Nigeria should not be an exception.

2.8 Formulation of Ceramic Bodies and Glazes from Natural Raw Materials

Over the centuries, attempts have been made by various researchers all over the world to develop workable ceramic bodies from earth resources. These efforts resulted in converting even the most common clays in combination with other minerals to produce useful and functional products that serve both domestic and engineering purposes. The use of ceramic materials in developing functional products that replace

steel and other metals in various functional capacities has continued to generate interest from researchers all over the world.

According to Conrad (1980) ceramic bodies are classified into the following, stoneware, earthenware, porcelain, white ware, and iron stone, etc. All these mature at various temperatures depending on the composition of various materials. Objects made from these include, dinner wares, sewer pipes, roof tiles, floor tiles, sanitary fixtures, engineering components, electrical components, cook stoves, balusters for building construction, bricks and the like.

Bray (2000) states that ceramic materials are classified into three to fulfil functional requirement. These are the forming materials which assist in the formation of structures. By forming, he meant materials that can deform, be imposed and have enough strength in unfired state to withstand handling. The second functional requirement for a workable body is the flux. These assist in the vitrification and sinterability of clay bodies and glazes. The third functional requirement is the filler which occupies the space left by clays and fluxes. Past researchers in the quest for suitable materials for various functional requirements abided strictly by this formula to obtain workable bodies.

There are several factors that inform the selection of materials for body formulation. Firstly, the ability of the ware to be shaped which necessitates the inclusion of plastic materials. Next is the ability of the ware to be bonded together during drying.

Secondly, the drying and firing of the ware without cracking which requires the inclusion of non-plastic materials that do not shrink, such as flint, quartz, and grog. And finally the third factor which is the fluxing of the body which involves the

incorporation of glassy materials to hold the body together when fired without allowing it to warp. This includes feldspar, nepheline and granite.

Experiments with the use of granite for the formulation of glazes began as far back as the beginning of the 20th Century, according to Grebanier (1975). Grebanier in his work titled "incorporating natural materials in glaze calculation" illustrated how materials like granite powder could be adopted to the empirical theory of glaze formulation.

Glazes are the principal component of any successful tableware and decorative ceramics. It is one of the means through which the ceramist expresses himself. It is one of the attributes that brings fascination and aesthetic appeal to the ceramic ware, apart from providing clean and hygienic surfaces.

The knowledge of materials and the behaviour of glazes of a particular mixture and processing methods is an exciting art in glaze making. Thus glaze making is regarded as a complex science but equally an interesting art. The colour outcome from addition of major fluxes, the effect of clay bodies on colour outcome and physical outlook, the effect of temperature variation of glazes and the atmosphere under which they are fired as well as methods of application provide a wide range of variations in the behaviour and appearance of glazes. This constitutes an unending source of information and avenues for more research.

There is hardly a single material in nature that makes a successful glaze (Nelson 1964). It is a combination of several materials rightly processed and formulated that makes a successful glaze. The use of granite in formulating glazes though not entirely a new art, yet has attracted very little interest among ceramic practioners. The materials used for ceramic production are hardly in a state of purity and fineness. They therefore require some basic processing before they are used. This view is supported by (Opoku

2007), who argued that the only way chemical purity and other physical properties are enhanced is by beneficiation.

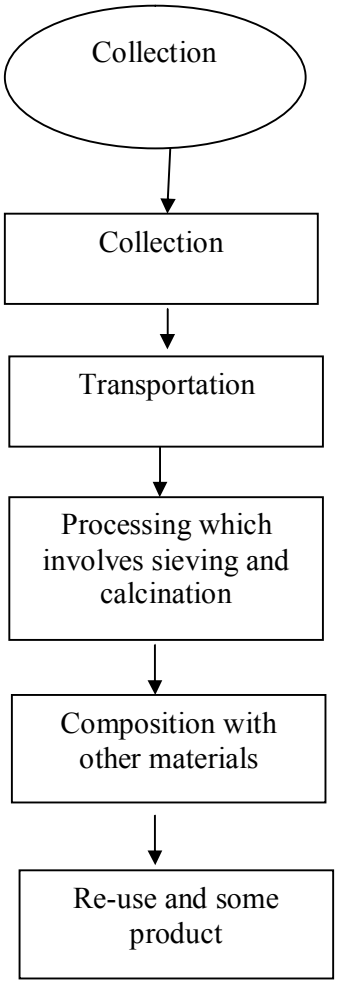
The advantage that granite offers is that, it is naturally processed through the process of quarrying and other treatments that follow are based on the desired result the potter wishes to obtain. With the economic constraints most potters face, it is important for potters to take advantage of unexplored areas of mining and beneficiation of industrial minerals so as to save cost and energy. This becomes the motivation for utilizing granite waste to develop glaze batches compatible with formulated ceramic bodies.

Findings from Grebanier's experiments showed the following characteristics: That granite powder produces dark brown glazes quite viscous and matures at 1260^0C, it is glossier and more fluid at 1280^0C. Below is the formula of the granite based glaze as shown by the author.

Granite powder	43.3%
Whiting	18.9%
Kaolin	6.8%
Flint	31.0%

Also shown below is a diagram illustrating a typical granite waste processing system.

Figure 2.1: Granite Waste Processing System



Source: Dijkema, et al (2000)

The industrial revolution in Europe and elsewhere contributed immensely in the development and improvement of ceramic bodies and glazes. However the twentieth century recorded remarkable advances in new applications for ceramic materials. Akinbogun (2005), citing Watchman (1982) remarks that although ceramic tools have been used since biblical times, they have of recent been used for various roles. These roles are found where high temperature strength is required as in furnaces, furnace

linings, rocket nose cones, heat engines such as gas turbines and components for possible automobile power plants and machines.

Based on these giant strides made by the ceramics industry in the development of global technology, there continues to be a widespread recognition of the potentials of ceramic materials and studies aimed at improving on their outstanding and unique qualities for varied applications in the industry is ongoing. Ceramic materials have facilitated the production of various artistic constructions, refractory elements, engineering elements and the likes. However this industry is poised for greater advancements as more materials are being adopted for new usage as asserted by (Akinbogun (2003). Today with such dramatic changes as the introduction of new materials and technologies coupled with the borderless nature of the industry, ceramics has engendered greater potentials than before. This research is aimed at building on the efforts made by previous researchers by characterizing and evaluating the suitability of granite sawing waste as an alternative material in the development of ceramic bodies for the production of decorative and aesthetic ceramics.

2.9 Tempering of Natural Clays for Body Formulation

Intentional tempering of clay was a common practice in antiquity especially when large vessels were to be made. Ceramists had various reasons for tempering their clays. The most important was the reduction of shrinkage during drying and firing, promotion of uniform drying of vessels and improvement of thermal shock resistance during firing. According to Kilikoglou, (1994), tempering has over the years enhanced the mechanical properties of the final products. This underscores the importance of this ancient practice. In modern times, the use of tempering as a drying agent is well known in several industries where clay products are made. The important technological

advantage this practice offers presents a constant need for more investigation. The granite, marble and quartz stone is known to be the chief material apart from straw and grog used in tempering clays. Stone is acknowledged to have infinitely influenced development since the history of man. Its use has evolved variously into different applications particularly in the building industry.

Nature has gifted mankind with large deposits of stone as natural minerals. Rania et al (2011) stated that world production of stone mineral reach the peak of some 75 million tonnes of quarry waste. During the processing of these stones, the raw stone block is cut either into tiles, slabs of various thicknesses or shaped into stones of specific sizes. They are also sometimes simply crushed by giant crushers, leaving various rock fragments and grain sizes, while the fine dust flies away into the air and settles on the ground or plants. For the processing of these stones into tiles and slabs, diamond blades are used and water is often introduced on the blade to cool the blade. This water absorbs the dust produced and is channelled into pits until the suspended particles settle. These pits are called sedimentation tanks. Then the slurry is collected in trucks and disposed of on the ground and left to dry.

Another solid waste generated by the Marble and granite industry is the waste which results from cutting slabs into the required dimensions. After the stones are cut to specifications, the slabs are finished either by polishing or texturing. The polishing operation is automated with the use of powdered abrasives that keep on scrubbing the surface of the marble or granite until it becomes smooth and shiny. Wastes from these operations are collected as by-products and reintroduced into clays. These scrap stone has monetary worth whether it is in the form of fragments, fines or waste water sludge. Instead of unconsciously discarding these materials, or storing them on site, identifying a second life for them is most desirable.

Stone pieces and grain size are determined by sieve analysis according to ASTM C136-01. Marble and granite particles grain sizes are determined by wet sieving according to ASTMD. 422-63. the nominal maximum aggregate size is 12.5mm and the coefficient of uniformity (CU) of the coarse aggregate is 1.9. Marble and granite slimy powder are of grain size not less than 75 microns.

These wastes are mixed either with cement for the production of bricks, or they are mixed with red clay for the production of bricks, roof tiles, and floor tiles. Nashville, (2012) indicates that there is a positive effect of granite slurry on cement bricks and ceramic products. Vekinis,Kilikoglou and Maniatis (1994) equally reported that quartzite stones were used for inclusion in red earthenware clays for toughening effects and other desirable effects. These no doubt were successful research efforts. However, these advantages present greater challenges and avenues for more research. This study hopes to undertake this offer by tempering local clays for the development of clay bodies suitable for casting ceramic wares.

2.9.1 Previous Analysis of Clays and other Minerals

Kilikoglou (1994), noticed that, even though the practice of tempering natural clays is wide spread, the effect of various non-plastic additives on some physical and mechanical properties of fired bodies are not well investigated. He opined that for these experiments to be deemed successful, a thorough analysis of these bodies must be carried out.

Hamer and Hamer (2004) describe such analysis as qualitative and quantitative. Qualitative determines only the nature of the parts present and quantitative determines the amount of each oxide present. The qualitative gives the percentage composition of a

substance and are grouped into similar parts for convenience. The analysis carried out by ceramists must combine quantitative and qualitative.

According to Hamer and Hamer (2004), there are three types of analysis. They describe the chemical content, the mineral content and the physical properties of a substance.

Analysis assists the assessment of a material in different ways but do not deny the necessity of practical tests. In ceramics, there are several analyses to be done to determine the chemical content and character of materials and products. These are fired analysis, rational analysis, comparative analysis, and mechanical analysis.

Fired analysis studies about how elements are converted into ceramic oxides. Rational analysis is ascertained by a combination of physical and chemical processes and therefore gives information about the raw material and some indications of its firing behaviour. Comparative analysis of materials is given as the interaction of all the materials combined their diversities and similarities.

Mechanical analysis is the analysis of materials that determines the grain and particle sizes. The sizes are either in coarse grading expressed as mesh size or extremely fine particle size measured by micrometres. Performance of structural materials such as heavy clays is critically dependent on their mechanical properties. Whether these clays are used in construction or in manufacturing of vessels, the properties provides the judgment that determines the effectiveness, efficiency, strength and durability of vessels so made.

In general, the test and analysis that are carried out were to determine the following: Physical properties such as:

- Dry strength
- Dry and fired shrinkage

- Plasticity
- Flow characteristics
- Porosity and water absorption,
- Stability of suspensions.
- Drying behaviour

While chemical properties of clay material and its particle size distribution, the level of cohesion purity and sinterability of material is determined by its particle size.

Plasticity is described as the inherent quality of clay to be controlled and shaped under different methods yet retaining its original shape. Sinterability is a term used when making reference to drying and firing behaviour of clay. This process help bring particles together under the firing processes thereby making the clay shrinks in size. Sintering produces the required strength and density needed in certain materials and function.

2.9.2 Properties of Clay Bodies

Singer and Singer (1963) defined properties as special attributes, a characteristic behaviour of clay materials under given conditions. The authors went further to classify clay properties under three groups. Group A refers to mineralogical composition. This represents the types and amount of mineral in each specie. The second in group A is the physical compositions; that is, particles sizes distributions and shapes of each mineral. The third under group A is the chemical composition.

The group B properties are the factors derived from group A. This refers to absorption rate and secondly, the packing and textual behaviour of clay minerals.

Group C are those physical properties controlled by absorption phenomenon and the packing and textual characteristics. These are:

(a) Dry strength and drying behaviour

(b) Drying shrinkage

(c) Plasticity

(d) Absorption

(e) Firing behaviour or vitrification.

Dry strength: Clay when exposed to air gradually gives up water constantly and slowly until the water is completely expelled out of the clay. During this process on constant rate period, the surface is moist and shrinkage begins to occur. The surface begins to dry as evaporation continues within the piece. The shrinkage rate that occurs at this point is equal to the volume of water expelled out of the clay. The general explanation is that, while the water separating the particles of clay evaporates, shrinkage continues to occur there-by making the particles come together and become bonded. When water is completely expelled, shrinkage no longer occurs. This process confers some major of strength to the body, enabling it to be handled in subsequent processes without it falling apart.

The strength of the clay is achieved when the clay body loses its water content. This is obtained less at room temperature than during oven temperature. The strength of dry clay is an important property with direct bearing on problems of moulding, handling and drying of wares. A high strength enables the clay to bear the weight of non-plastic materials such as feldspar, flint and grog. According to Singer and Singer ibid, the green strength of clay is generally determined by finding its transverse strength and expressed as modulus of rapture which has volumes ranging from 20 - 1500 ib/in^2 (1.4 to 105 kg/cm^2 CR 28).

Shrinkage: Shrinkage is the ability of clay to reduce in size. Several factors combine to effect shrinkage of a given body. The first is the particle size of clay mineral. According to Singer and Singer ibid, the lesser the grain size of a clay mineral, the

higher the shrinkage. The second is the atmospheric conditions during drying and firing.

Datiri (2007) noted that the determination of clay mineral particles during preparation is an important factor in measuring differential shrinkages. The significance of knowing the shrinkage rates of clay and clay bodies lies not only in determining the fired sizes of ware but also in adjusting the firing schedule to reduce the speed volume of changes. In order to obtain ware of the same size throughout a kiln setting, it is important to sustain a certain temperature for a long time for reaction to be complete. Where the volume changes in shrinkage are rapid, problems are likely to occur such as cracks.

Shrinkage can be controlled by addition of grog without necessarily changing the composition of a body. This makes it not to shrink during the second firing. Shrinkage can equally be increased without changing the composition of a body. This can be done by adding to the clay a raw material that burn off completely e.g. saw or coal dust.

Plasticity: The term plasticity as it relates to clay refers to the ability of clay to take water at a given quantity and can deform under pressure without rapture and is able to retain its shape when the pressure is released. If it is then dried, it loses its ability to deform as it becomes hard and brittle. Thus plasticity is a highly important property of clay.

Several factors combine to acquire plasticity. The chief among them is the flow of particles sizes over each other and the amount of water inherent in the clay material. Shrinkage is affected by the following mineralogical composition.

(a) Particles size and particle size distribution

(b) water.

Plasticity of clay therefore depends on the nature of fine fraction of clay and greater bonding of water to the clay surface. It can be measured by its ability to resist fracture and maintain a very large degree of pliability- retaining its shape without cracking. It is less pervious to water and can be placed in water for ten minutes without disintegrating. Moisture absorption is less. This quality or property of clay is necessary to enable objects bonded together and retain their form when manipulated during production.

2.9.3 Absorption Phenomenon

There is a relationship between particle size of clay and the rate of absorption of water films around in between the particles. Singer and Singer, (1963) observed that the ability of water to pass through a layer therefore depends on the particles size and the degree of firing. Plastic clays known for their fine particle size tends to absorb less water compared to non-plastic clay which has larger particle sizes.

Harmer and Harmer ibid, noted that in every plastic clay, interstitial spaces between clay and other minerals are occupied with water. During firing to a temperature range of 600^0C this water escapes, living empty spaces. This leaves the body extremely porous. At higher temperature, the felsparthoid and silicon elements fuses, resultant molten silicates begin to occupy the spaces left. This results in greater densification, living the body less porous.

Generally, potters seek to obtain zero porosity in their wares. However, it recommended that a slight porosity of 1 - 2% should be left as it is observed that this gives the body much stronger tensile strength. This is because, the glassy nature of the former is brittle and allows no chance of movement between particles except when broken.

The level of porosity of ware is determined by simply taking a piece of fired body when warm and weighted accurately preferably on scientific scale. The test piece

is submerged in boiling water for five minutes and left in the water to cool. The test piece is now taken from water and dried with a damp sponge. The test is then weighted again and the increase in weight is calculated as a percentage of original dry weight. Fired clays generally have porosity values between 5% and 10% in stone wares.

Vitrification: Many ceramic raw materials are composed of refractory elements which remain solid at high temperature. To lower their temperature require the introduction of low-melting fluxes while some ceramic materials have definite melting point, many do not have definite melting point but melt progressively leading to complete fusion. Some have simple melting behaviour. Thus many empirical tests are usually conducted by heating the material at certain temperature and withdrawing it at intervals to determine the extent of fusion.

When clay is heated to a higher temperature, water is driven off and in due course becomes hard. Vitrification at this point begins to occur, leading to a strong dense piece. This however softens later and fuses as heating progresses. During this reaction, expansion and overall shrinkage occurs. The series of reactions are predicated on the mineralogical, chemical and grain size composition of clay.

It is generally concluded that ceramic properties are chiefly dependent on the mineralogical composition and the grain sizes of clay. There is thus, a correlation between particle size, with drying shrinkage, firing shrinkage and apparent porosity. It is found out by Harmer and Harmer (2004) that there is more correlation between drying shrinkage and particle size and its grading. There is also some relationship between particle size and firing shrinkage. The coarser clays shrink less. Also noted by these researchers is that particle sizes determine the level of porosity of fired clay.

2.9.4 Clay Types and Uses

Clay is a generic term for hydrated silicate of alumina according to sullayman (2006) It is a heavy, damp, plastic material that cakes when exposed to dry heat and can change and become hard and impervious when further subjected to higher temperatures.

Clay possesses inherent qualities which potters depend on for various results. These properties define its ability to be formed and deformed and can completely change to new materials when fired to high temperatures. Although clay is used for other things, its primary use in ceramics is for the production of bricks, tiles, sanitary wares, table wares, electrical insulators and heat insulators. It is also used in cosmetics and as filler in rubber and paper.

Clays which occur in their place of origin are called primary clay. One of the most important characteristics of kaolin is the fact that it is found in-situ-(its place of formation). Being the end product of several geological processes, they are referred to as residual clays. These are popularly called china clay or kaolin. Sullayman ibid, associates the name Kaolin to the Chinese, indicating the location in which it was discovered. According to him, Kaolin derives its name from Kaolinite; Kaolin is thus a derivation from Kao-liang, Jinxi, and a Chinese word for high ridge. The chemical formula for Kaolin is $Al_20x2Si0_2x2H_20$.

This clay results from decomposition of granite, feldspar and pegmatic rocks. Primary clay also called residual clays is mined from their position of origin in which they decompose from the parent rock. It is free from colouring impurities. It is white, short or low in plasticity and possesses large particle sizes and fires at very high temperature. Principally, it is used in bodies to give whiteness, clarify colours and to control vitrification. Ahuwan et al (2001) also stated that in glazes, it is useful in

controlling fluidity at slop stage. It equally controls viscosity during molten stage and adds stability to the final glaze.

2.9.5 Secondary Clays

These are also called sedimentary clays. They are clays that have been deposited in their present location by the action of water or ice. By this action of weathering, particles sizes are further broken down thus producing finer clay that is more plastic than primary clay.

Most secondary clay contains impurities of which iron is the most common, giving a grey, brown or cream colour. Because of the organic matter collected along the way, it could be dark in colour and is often with bad smell. Ball or plastic clay comes under this classification. Some are highly plastic and are used as additives to clays lower in plasticity. Plastic clay is also called long clays and fat clays. They are strong and can withstand vigorous handling during forming. This clay shrinks more because of its plasticity and fine particle size.

2.9.6 Mould Preparation

It must be noted from the onset that, the choice of a particular material necessitates the use of casting method for the production of wares, hence the need for the production of plaster moulds

Several stages are involved in the making of plaster moulds. First, the original model is made out of wet clay. It is usually advisable that the original block clay model be made and finished with great care so as to eliminate those areas that could be non-functional or too difficult considering the possible shrinkage rate that would likely occur. Shrinkage actually occurs in the dry and firing stages of production, thus the model must be made slightly oversized so that desirable size could be achieved.

From the original model a positive cast is made in plaster know as the case mould. Traditionally, the most commonly used material for mould making is plaster of Paris. There are various plasters of different hardness and setting rates used in the production of moulds. It is advisable that one chooses the one that sets faster. Theoretically, 18.6 pounds of water will set 100 pounds of plaster according to Nelson ibid. However, studio practice could prove otherwise depending on several variables. The function of the mould is to reproduce the required profiles and extract water from the body of clays. Usually, when a larger amount of water in proportion to the plaster is used, the porosity is high while the strength and durability of the mould is reduced.

2.9.7 Slip Casting

Slip casting is one of the major processes employed in bringing out ceramic forms. The process involved is always simple. Local clays brought from various sources are reduced to liquid or viscous state and thoroughly mixed to remove air bubbles. The slip is then allowed to stay for about 15-30 minutes depending on the porous level of the mould.

The amount of time the slip stays in the mould depends largely on the absorbent capacity of the mould and the thickness required of the cast wares. Moulds that have high porosity absorb water from the clay slip faster, and this also depends on the ratio of water to plaster.

Wensley (2002) noted that each casting causes the plaster mould to become less absorbent (being wetter), but moulds can be re-dried for high absorbency. So, second and subsequent castings will take progressively longer to build up similar wall thickness. After the desired thickness is achieved, excess slips are poured out into the container.

Following this, clay coatings on the mould are allowed to form and shrink away from the mould to create allowance that would make easy removal possible. Wensley (ibid), advises that potters should be prepared to adjust the consistency of the slip by adding more water after some two on three castings in order to assist the filling of moulds.

There are three stages in testing a clay body for its castibility.The first is deflocculation; that is the determination of the optimum water and deflocculant additions to give a slip that holds the non-plastic materials in suspension without dependence on thixotropy.

The second is the viscous characteristic. That is making sure that slip is not thioxtropic that blockage will occur in pipelines. And the last is the setting rate. That is the ease of disengagement of the cast ware from the moulds and the strength required.

2.9.8 Firing

The final step involved in the production of ceramic wares is firing. This process is the ultimate and most crucial because it introduces strength and other mechanical qualities to the body. Sintering, density, and performance are achieved by this process. Licio (2002) describes this process as a stage in which green (unfired), mechanically weak, or newly formed piece of work is transformed into a strong durable product.

It is also the processing operation at which production errors or flaws that may not be noticeable during manufacturing will be made manifest. Loading and firing of wares is considered a very delicate process because any carelessness can mare the entire effort of a potter.

Two stages are involved in this process of firing. The first stage is bisque firing. This is done after the wares are dry and almost moisture free. The recommended firing

temperature is 900-l000^{o}C depending on the type of clay and the result one wants to obtain. At this stage, the wares are hard enough to withstand handling especially during glaze operation, and sufficiently absorbent to attract or suck glaze.

The second firing is referred to as gloss firing to stoneware temperature. The temperature required for this firing ranges from 1200-1300^{0}C. Michelle (1995), affirms that this process apart from helping the glaze to melt and fuse to the body, it makes the ware to almost attain its maximum strength. It achieves complete sintering, closes the pores in the body, creates density and imparts strength and permanence to the body.

CHAPTER THREE

3.0 Research Methodology

The research methodology adopted for this study is experimental as well as studio laboratory research as suggested, by Mbahi (2001). The granite waste and other minerals were randomly sampled within Kaduna State and brought into the ceramics studio at Ahmadu Bello University, Zaria, Nigeria. All initial or preliminary experiments are conducted in the studio indicated above, while the analyses of samples were done at the Defence Industries Corporation (DIC), Kaduna.

3.1 Materials Sourcing

In developing this research, conventional ceramic raw materials such as clay, and granite sawing waste of fine grain size were used. The ball clay was obtained from Bomo village (Sabon - Gari Local Government Area of Kaduna state while kaolin was sourced from Kankara in Katsina State.

Basically, clay can be classified into two types: Primary/residual clay and secondary/sedimentary clay or simply, kaolin/china clay and ball clay. Kaolin is less plastic and contains larger particle sizes. It is white in nature and fires at an extremely high temperature. Moreover, the kaolinitic nature and the presence of aluminium hydroxide confer a refractory behaviour which impairs sintering during firing in some cases. These results in greater porosity associated with elevated values of water absorption which reduces the mechanical strength of forms. This is confirmed by Monteiro et al, (2003).

The second type of clay sourced is ball clay. This clay has fine particles size and therefore more plastic in nature. Sometimes this high plasticity becomes a disadvantage as it often times causes some dimensional defects during drying and firing. Based on

this observation therefore, two clay samples kaolin and ball clay were sampled for body formulation. The focus was to achieve a body that will take care of these two extreme inadequacies or shortcomings associated with the kaolin and ball clay. As such, this research reformulated a ceramic body composition by adding non-plastic materials to reduce plasticity and a fluxing agent to condition the refractoriness of kaolin for improved sinterability during firing operation.

According to Nashville, (1995) one technological method which is already being tested to decrease porosity is the incorporation of granite wastes. As earlier stated, granite is a rock with large amount of quartz, feldspar and mica. During the early hours of firing, these materials act as non-plastic agents which permit the use of lower amount of water in body formation which facilitates drying. During firing, the quartz behaves as an inert material but may partially dissolve in liquid phases should they occur. Both feldspar and mica play the role of liquid formation and lowering of the porosity of fine ceramic product, thus enabling quartz to dissolve.

Based on the aforementioned considerations, the research considered two variables in an attempt to solve the research problem. These are the need to improve the two clay types sampled and the adaptation of granite waste as an additional raw material. The central emphasis was to formulate ceramic bodies by the addition of granite waste, as well as providing a final destination for waste, thereby solving a part of environmental problem.

3.2 Equipment/tools and facilities

In conducting these experiments, equipment such as the ball mills, test kilns, weighing machines as well as modelling tools were utilized. These were sourced from

the ceramics studio and multi-purpose laboratory in Chemistry Department, Ahmadu Bello University, and Zaria.

3.3 Analysis of Materials and Body Formulation

Many potters have given instructions on the best way to compound clay bodies. According to Cooper and Lewenstein (1988), clay bodies are obtained by blending of various clays, feldspars, fluxes, opacifiers, modifiers and other ceramic materials in combinations for use at high and low temperatures.

Conrad (1980) observed that very few clays or minerals have the desired properties for any given purpose if left alone as they occur in nature. Hence various clays types or minerals are selected for their particular contributions to make up a workable body. Grebanier (1975) also noted that ceramics has many contributing and diverse elements that must be put together for any effective result to be achieved. The highest technical standard hoping to be achieved by this research is anchored on the experience of previous potters such as Cooper and Lewenstein ibid, as well as Conrad 1980 and Nelson (1964),'etc.

There are several properties that are usually desirable in a workable body. These are handling properties, dry strength, and firing properties. In some cases, materials are added because they offer an in expensive' body constituent, while in others, they contain and produce a desired chemical composition or a physical attribute. Thus, most clays types used for throwing, casting, hand building are a blend of several clays, (Conrad, 1980). More so, a wide range of shaping methods creates the need for variation in the make-up of clay bodies. This is because the clay that would be considered workable for one process may not be suitable for another. Based on these factors, the materials for this research were selected based on three considerations: -

properties for a workable body, desired chemical compositions for a workable body and produceability of the workable body, see table 3.1 and 3.2 below;

Table 3.1: Properties and Characteristics inherent in the selected Materials

Type	Plasticity	Softening point	Colour	Absorption	shrinkage	Grain size
Kaolin	Low	1650^{O}c	Strong white	Low	Low	Moderate
Ball clay	High	1225^{O}c	Gray, brown, buff, black etc.	Moderate	High	Fine
Granite	None	12,000	Gray	Low	Low	Fine

Source: Conrad (1980)

Table 3.2: Body Problems and their likely Solutions

Problems	Correction/Solution
Too plastic and sticky	Decrease ball clay and add non plastic clay
Non plastic	Add ball clay or bentonite
High shrinkage and warpage	Reduce ball clay, add kaolin, and silica, decrease flux
Fired brittle	Fire at lower temperature, increase kaolin and silica or decrease flux
Low vitrification	Add kaolin or silica
High nitrification and porosity	Add granite, fluxes and modifiers
Low sinterability	Add flux, granite, decrease kaolin and silica

Source: Cooper and Lewenstein (1978)

A summary of table 3.2 above indicates that non-plastic clays are difficult to handle and use hence they break easily in the cause of handling. They fire at very high temperatures and create high water absorbency or high porosity and then low thermal or mechanical strength. Non-plastic materials also have low sinterability.

Plastic clays on the other hand have low vitrification temperature and shrink highly, as well as distort easily at dry and firing states. They may be too sticky and unfavourable for some usage. They equally have unclean and dark colours and so unsuitable for some particular effects.

Based on these considerations therefore, this researcher selected materials that assisted in correcting these defects. This includes addition of granite waste at varying proportions in addition to other materials such as, kaolin and ball clay.

3.4 Chemical Analysis of Materials

Below on tables 3.3 to 3.9 are the tables showing the chemical analysis of materials samples utilized for this study.

Table 3.3: Ball Clay

Compound	Al	Si	S	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Ag	Eu
Conc unit	17.9 %	56.4 %	0.085 %	4.17 %	1.57 %	1.89 %	0.075 %	0.025 %	0.040 %	14.10 %	0.033 %	3.47 %	0.20 %

Source: Defence Industry Corporation Multi-purpose Science Laboratory, Kaduna State.

Table 3.4: Granite

Compound	Al	Si	S	K	Ca	Ti	V	Mn	Fe	Cu	Zn	Ba	Eu	Re
Conc unit	11.8 %	59.4 %	0.089 %	11.3 %	5.06 %	1.22 %	0.032 %	0.19 %	10.33 %	0.026 %	0.058 %	0.35 %	0.16 %	0.09 %

Table 3.5: Kaolin

Compound	AI	Si	K	Ca	Ti	V	Mn	Fe	Ni	Cu	Ga	Re	Ti
Conc unit	37.1 %	56.7 %	2.00 %	0.69 4	0.69 4%	0.15 3%	0.00 5%	0.06 0%	2.23 %	0.04	0.069 %	0.17	0.70

Table 3.6: Chemical Analysis of Batch GBC1 mixture (wt%)

Batch type	Chemical composition								
	$Al_2^O{}_3$	SiO_2	Na_2O	K_2O	TiO_2	TiO_2	mgO	Fe_2O_3	CaO
GBCI	25.94	48.84	0.46	1.91	1.30	0.83	9.14	1.30	9.90
GBC1	26.74	50.67	0.67	2.24	1.24	0.82	9.14	1.40	9.86
GBC1	22.64	56.16	1.08	2.89	1.13	0.80	7.72	3.78	5.78
GBC1	21.54	54.33	1.08	2.89	1.07	0.8	7.24	3.78	5.98

Table 3.7: Chemical Analysis of Batch GBC2 mixture (wt%)

Batch type	Chemical composition								
	$Al_2^O{}_3$	SiO_2	Na_2O	K_2O	TiO_2	TiO_2	mgO	Fe_2O_3	CaO
GBC2	25.94	48.84	0.46	1.91	1.30	0.83	9.14	2.30	8.90
GBC2	26.74	50.67	0.67	2.24	1.24	0.82	9.14	2.40	7.86
GBC2	22.64	56.16	1.08	2.89	1.13	0.80	7.72	2.78	6.78
GBC2	21.54	54.33	1.08	2.89	1.07	0.8	7.24	1.78	6.98

Table 3.8: Chemical Analysis of Batch GK1 mixture (wt%)

Batch type	Chemical composition								
	$Al_2^O{}_3$	SlO_2	Na_2O	K_2O	TiO_2	TiO_2	mgO	Fe_2O_3	CaO
GK1	28.94	45.84	0.46	2.81	1.30	0.83	9.14	0.30	10.90
GK1	27.74	49.67	0.67	2.24	1.24	0.82	9.14	0.40	9.86
GK1	32.64	46.16	1.08	2.89	1.13	0.80	7.72	0.78	7.78
GK1	31.54	44.33	1.08	2.89	1.07	0.8	7.24	0.78	7.98

Table 3.9: Chemical Analysis of Batch GK2 mixture (wt%)

Batch type	Chemical composition								
	$Al_2^O{}_3$	SlO_2	Na_2O	K_2O	TiO_2	TiO_2	mgO	Fe_2O_3	CaO
GK2	28.94	45.84	0.46	2.91	1.30	0.83	9.14	0.30	10.90
GK2	27.74	49.67	0.67	2.24	1.24	0.82	9.14	0.40	8.86
GK2	32.64	46.16	1.08	2.79	1.13	0.80	7.72	0.78	7.78
GK2	31.54	44.33	1.08	2.89	1.07	0.8	7.24	0.78	7.98

3.5 Batch composition and Recipe

On a general note, most body recipes are compounded either from clay materials or from blending different prepared bodies together. The method used by this research is that of blending different clay powders from different materials together at different percentages and mixed by hand with the aid of water since the quantities desired for experimentation are small. The coning and quartering procedure and technique of mixing materials suggested by American Society for Testing Materials (A.S.T.M) was adopted. Samples made and tested were classified into four, comprising of sixty three batches represented in a triaxial draft as indicated in tables 3.10 to 3.27 and in line with figure 2.2 below:

Table 3.10: Batch of the Sole Base Material Recipe

Granite Waste	100%

Source: Studio Experiment by the researcher.

Table 3.11: Batch of the Base Material and Ball Clay

Granite waste	90%	80%	70%	60%
Ball clay	10%	20%	30%	40%

Table 3.12: Batch of the Base Material and Kaolin

Granite waste	90%	80%	70%	60%
Kaolin	10%	20%	30%	40%

Table 3.13: The Base Material in Combination with Ball Clay and Kaolin

Granite waste	80%	
Ball clay	10%	
Kaolin	10%	

Table 3.14: Base Material and Ball Clay/Kaolin

Granite waste	70%	70%
Ball clay	20%	10%
Kaolin	10%	20%

Table 3.15: Base Material and Ball Clay/Kaolin

Granite wastes	60%	60%	60%
Ball clay	30%	20%	10%
Kaolin	10%	20%	20%

Table 3.16: Base Material and Ball Clay only Batch 1

Granite	50%	40%	30%	20%	10%
Ball clay	50%	60%	70%	80%	90%

Table 3.17: Base Material and Kaolin only Batch 1

Granite	50%	40%	30%	20%	10%
Kaolin	50%	60%	70%	80%	90%

Table 3.18: Base Material and Ball Clay/Kaolin

Granite	50%	50%	50%	50%
Ball clay	40%	30%	20%	10%
Kaolin	10%	20%	30%	40%

Table 3.19: Base Material in Combination with Ball Clay /Kaolin

Granite	40%	40%	40%	40%	40%
Ball clay	50%	40%	30%	20%	10%
Kaolin	10%	20%	30%	40%	50%

Table 3.20: Base Material in Combination with Ball Clay /Kaolin

Granite	30%	30%	30%	30%	30%	30%
Ball clay	60%	50%	40%	30%	20%	10%
Kaolin	10%	20%	30%	40%	10%	60%

Table 3.21: Base Material in Combination with Ball Clay and Kaolin

Granite	20%	20%	20%	20%	20%	20%	20%
Ball clay	70%	60%	50%	40%	30%	20%	10%
Kaolin	10%	20%	30%	40%	50%	60%	70%

Table 3.22: Base Material in Combination with Ball Clay and Kaolin

Granite	10%	10%	10%	10%
Ball clay	80%	70%	60%	50%
Kaolin	10%	20%	30%	40%

Table 3.23: Base Material in Combination with Ball Clay and Kaolin

Granite	10%	10%	10%	100%
Ball clay	40%	30%	20%	10%
Kaolin	50%	60%	70%	80%

Table 3.24: Ball Clay with Kaolin Batch 2

Ball clay	90%	80%	70%	60%	50%
Kaolin	10%	20%	30%	40%	50%

Q3

Table 3.25: Ball Clay with Kaolin Batch 3

Ball clay	40%	30%	20%	10%
Kaolin	60%	70%	80%	90%

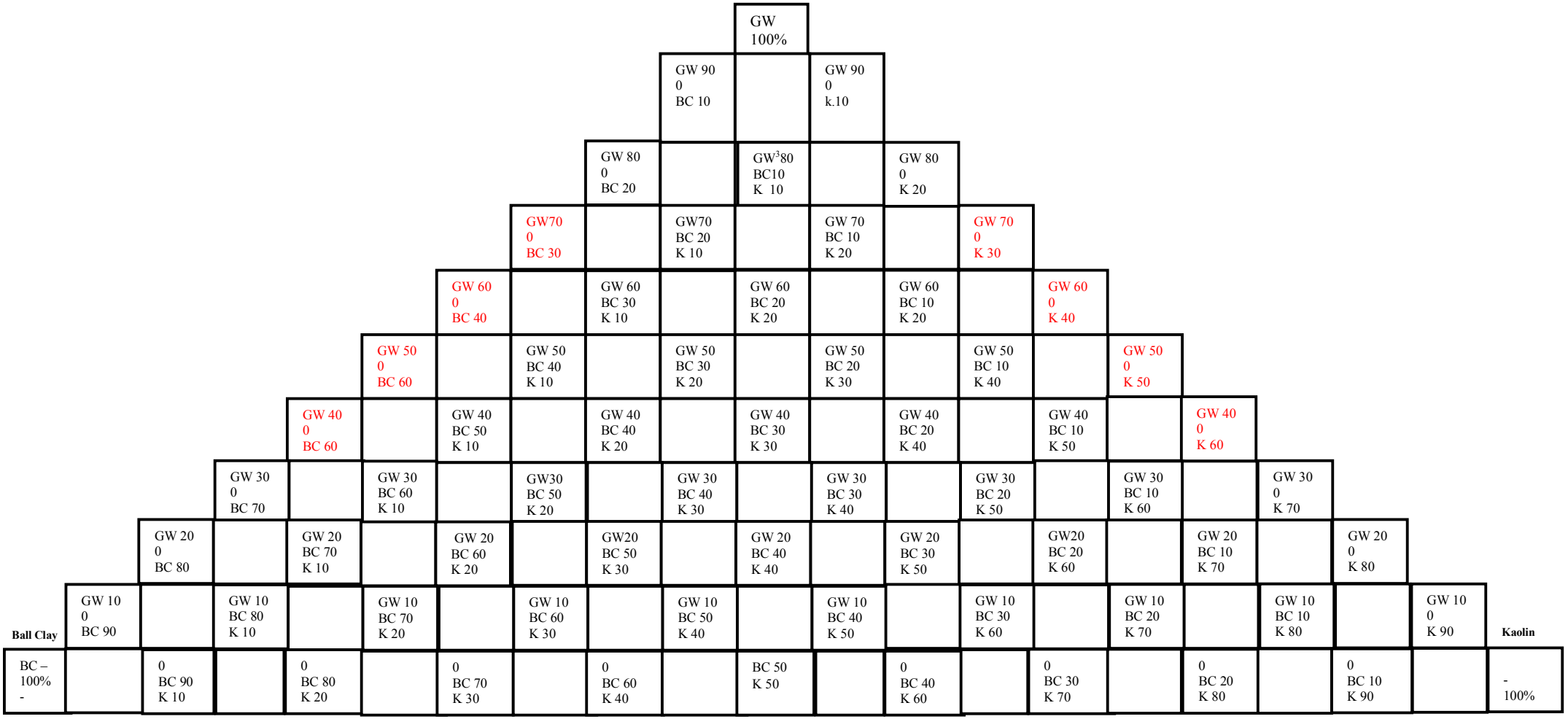
Table 3.26: Ball Clay without any Additives

Ball clay	100%

Table 3.27: Kaolin without any Additives

Kaolin	100%

Figure 3.1: Triaxial Blend of Composites



Source Gukas, (1986)

According to Grebanier, ibid, granite powder produces dark or dirty brown colour which does not promote colour brilliance after gloss firing. To this end, this research considered the possibility of improving the colour purity of the granite based body by adding kaolin to promote brightness of the body in order to achieve a bright colour after glaze application and firing. Table 3.12, and 3.17-28 above shows the body composition designed to achieve the above mentioned effect.

Tables 3.11, 3.13, 3.14, 3.15, 3.16 and 3.18 - 3.25 have no other special consideration than the possibility of deriving a simple workable casting body for the purpose of ceramic production. All the above batches were converted from percentages to grams, representing 1 kilogram per sample. Samples in Tables represented above were labelled for the purpose of identification (GBC) which is granite and ball clay. Others were labelled (G BC K) which represents granite, ball clay and kaolin. While (GK) represents granite and kaolin

3.6 Slip Preparation, Casting and Firing

It is already stated in this study that there are a wide range of production methods which necessitate the variation in clay body composition and preparation. A ceramic body which may not be suitable for one application may be suitable for another. Since the objects produced were to be done through slip casting, this required a body composition that could meet the entire requirement for easy casting such as slip suspension, viscosity and thixothopy. Except for the purpose experimentation was hand building and throwing methods employed to test the workability of the new bodies formulated.

The granite waste in combination with other materials brought from various sources was compounded based on their projected workability parameters. The

materials were reduced to liquid or viscous state. These were thoroughly mixed by hand to eliminate unwanted properties and to ensure a homogeneous mixture. The various slip compositions were then poured into different hollow absorbent moulds and allowed to stay between 10 - 20 minutes. As soon as a reasonable thickness that could withstand pressure from handling, and the required weight that is able to withstand firing suitable for the desired use were achieved, excess clay slip was poured out. Following this, the clay coating on the mould was allowed to harden and shrink away from the mould to create allowance that would make easy removal possible. These products were dried within three days under room temperature and fired to bisque and gloss temperatures. By this process, 15 samples were caste as free standing small containers to determine the structure capability of these materials.

These cast wares were allowed to dry slowly equally under room temperature within three days and others exposed to rapid drying out side in an open area and within one day, drying was complete. This was done in order to determine their behavioural patterns when exposed to these two varying drying atmospheres. As noted by Mangels et al (1984), bodies that have low porosity tend to dry very slowly and high incidences of shrinkage and deformation or distortion of form and sometime, serious cracks occur. This is made more imminent when it is exposed to excessive dry air, while bodies with high porosity dry very fast with low incidences of shrinkage, distortion and cracking even when exposed to drastic drying atmosphere. Since these two bodies potentially have all of the above mentioned characteristics, it was necessary to expose them to these two drying atmospheres to establish their behaviour to ensure conformity to set standards.

After exposure to the two drying atmospheres, the following tests were conducted:

a. Shrinkage rate,

b. Handling properties e.g. ware hardness, for easy handling,

c. Dry rate of distortion, deformity or stability of form,

d. Plasticity and cohesion of the body

e. Firing temperature

f. Glaze adhesion

After ensuring that wet drying was successfully accomplished, the samples were subjected to a firing temperature ranging from 900^0C- 1200^0C. Each category of samples were subjected to these varying degrees of firing to determine at which temperature the appropriate properties would be achieved and characteristics recorded. Plates1-7 below indicates the plaster moulds, caste pieces at green and at fired stages.



Plate 1: showing plaster moulds



Plate 11: Another set of Plaster Moulds Ready for Casting

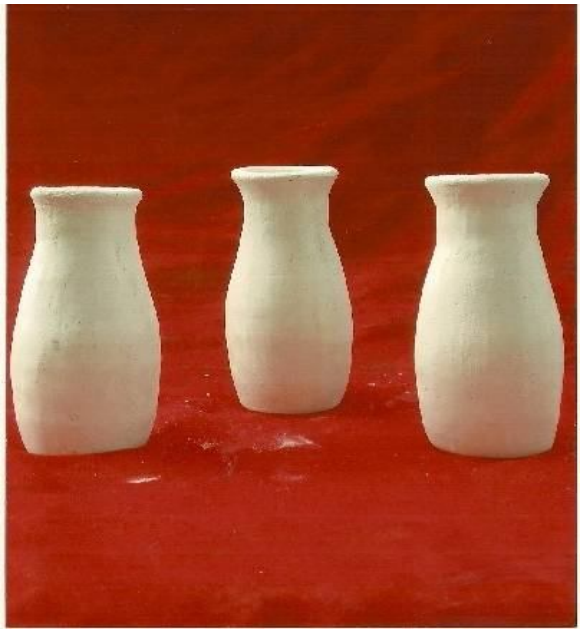


Plate III: Cast product ready for for firing



Plate IV: cast products in green state ready for firing



Plate V(a): Cast bowls in green stage from batch GK1

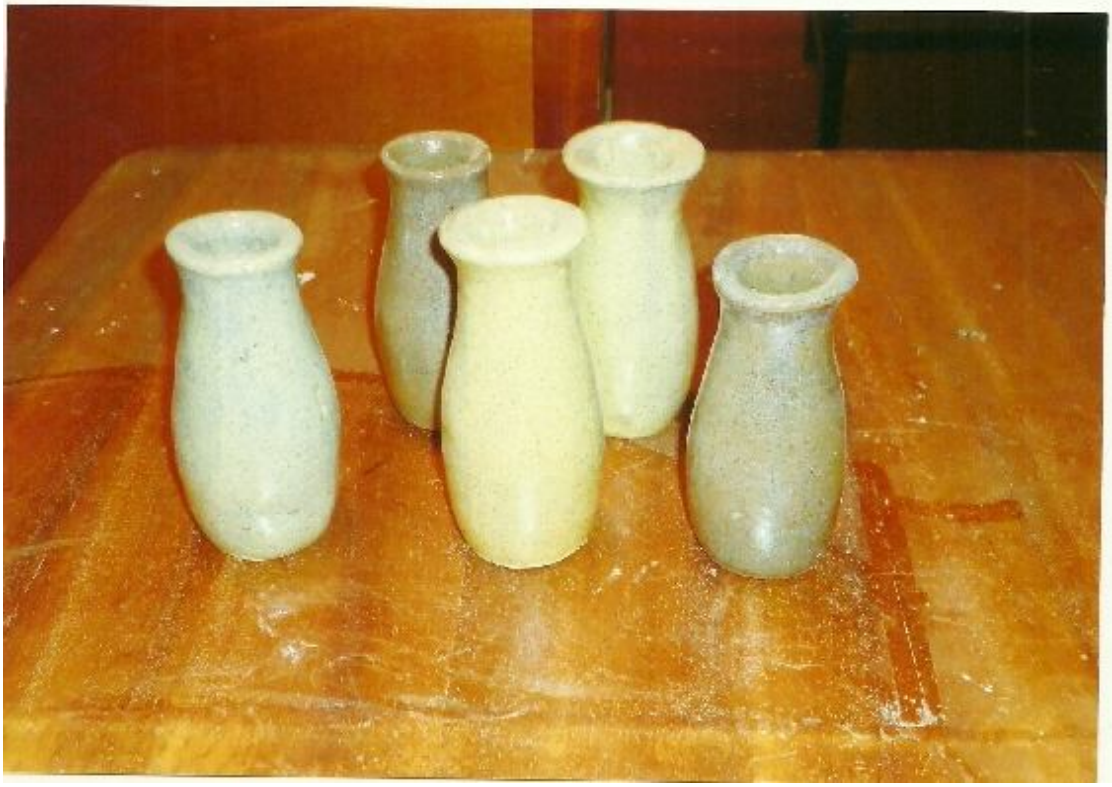


Plate V(b): Cast wares in green stage from batch GK2



Plate VI (a): Cast bowls in green stage from batch GBC1

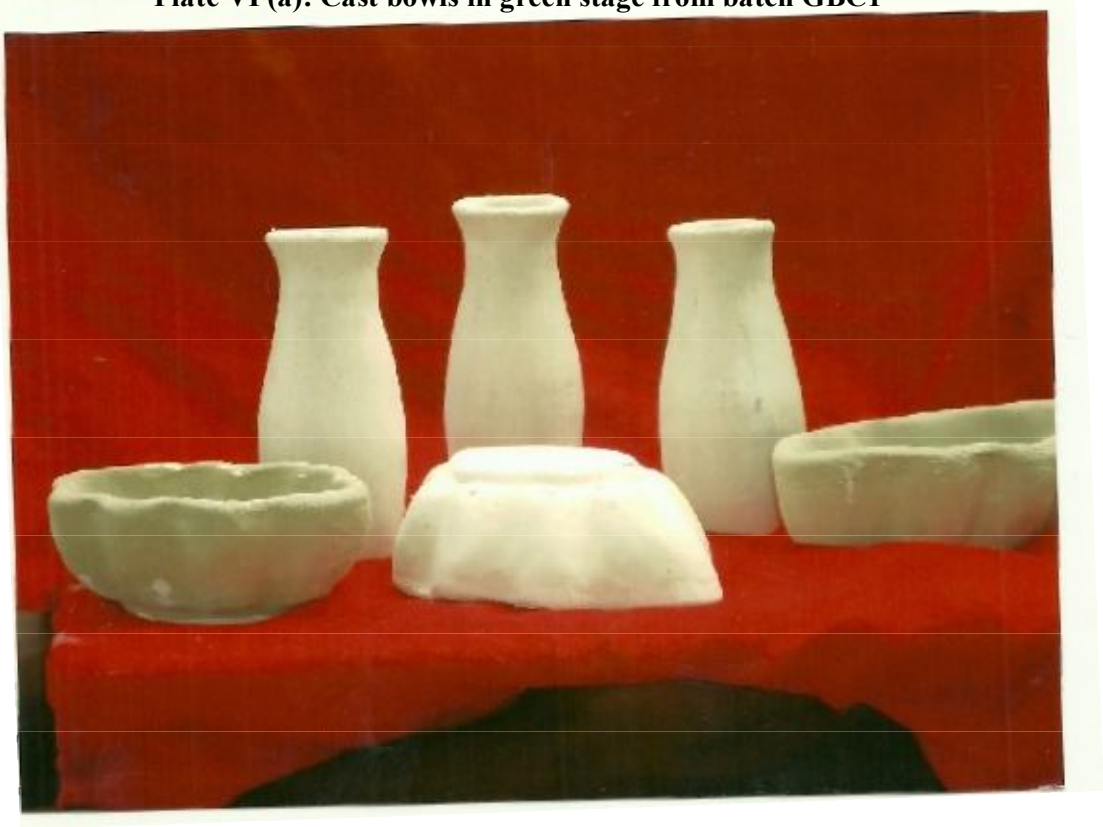


Plate VI(b): Samples of Products in Green Stage from GBC 2



Plate VII(a): Samples of Glaze Fired Product from GK1 & 2



Plate V11(b): Samples of Glaze Fired Product from GBC 1&2

3.7 Determination of Physical and Chemical Behaviour of Composites

Clay bodies formulated were grounded into fine particles and taken to Defence industries Corporation (DIC), Kaduna for chemical analysis as suggested by (Hamer and Hamer ibid. The X-ray Fluorescent Spectrum (XRF) of the samples was conducted with the use of computer to determine the compounds and elements present in those materials. This is shown in Table 3.3 - 3.9.

The second set of samples was made for the purpose of determining the shrinkage rate, water absorption rate, sinterability of the body and glaze adhesion. Test bars of 2x4 cm were made and a line drawn at the centre of the test bar when the composite was wet. Upon drying, the measurement was taken. Samples were fired to 1200c and again, measurement was taken. The following is the shrinkage calculation and as represented in fig 3.1 to 3.8 and table 3.2.8 below.

Dry Shrinkage Test

Sample GBC1 wet length = 4 inches

Dry length = 3.6 inches

$$\% \text{ shrinakge} = \frac{wet\ lenght - dry}{wet\ lenght} \times \frac{100}{1}$$

$$= \frac{4 - 3.6}{4} \times \frac{100}{1} = \frac{0.4}{4} \times \frac{100}{1} = 10$$

Sample GBC1 wet length = 4 inches

Dry length = 3.6 inches

$$\% \text{ shrinakge} = \frac{wet\ lenght - dry}{wet\ lenght} \times \frac{100}{1}$$

$$- \frac{4 - 3.6}{4} \times \frac{100}{1} - \frac{0.4}{4} \times \frac{100}{1} - 10$$

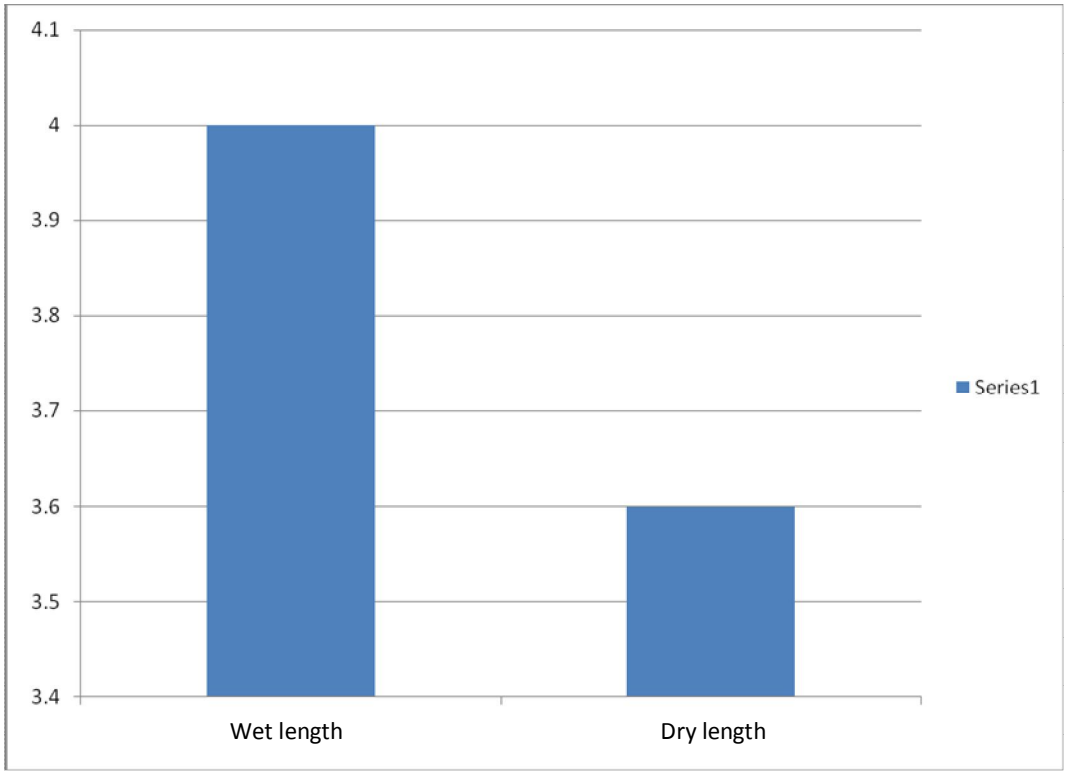


Figure 3.3: GBC 1 Dry Shrinkage Test

Graph Representing Sample from Batch Combining the Base material/Ball Clay 1

Samples GBC2 wet length = 4 inches

Dry length = 3.7 inches

$$\% \text{ shrinakge} = \frac{wet\ lenght - dry}{wet\ lenght} \times \frac{100}{1}$$

$$= \frac{4 - 3.7}{4} \times \frac{100}{1} = \frac{0.3}{4} \times \frac{100}{1} = 7.5$$

Samples GBC2 wet length = 4 inches

Dry length = 3.7 inches

$$\% \text{ shrinakge} = \frac{wet\ lenght - dry}{wet\ lenght} \times \frac{100}{1}$$

$$= \frac{4 - 3.7}{4} \times \frac{100}{1} = \frac{0.3}{4} \times \frac{100}{1} = 7.5$$

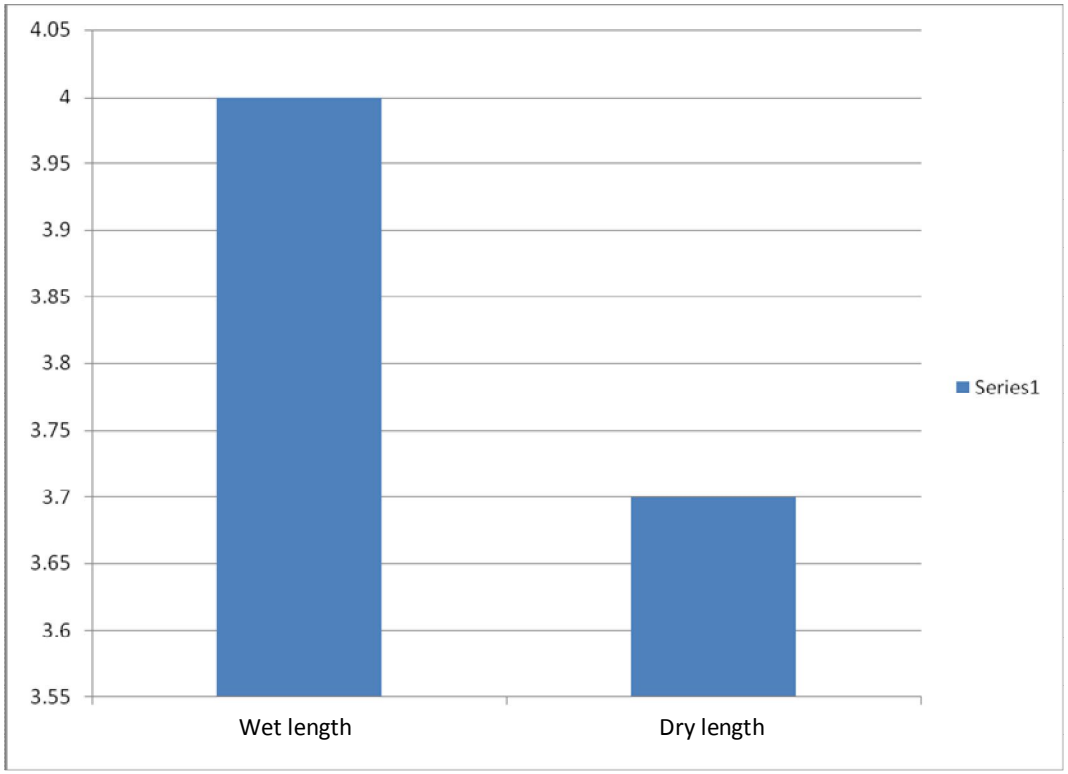


Figure 3.4: GBC 2 Dry Shrinkage Test

Graph Representing Samples from Batches combining the Base material/Ball Clay 11

Sample GK1 wet length = 4 inches

Dry length = 3.7

$$\% \text{ shrinakge} = \frac{wet\ lenght - dry}{wet\ lenght} \times \frac{100}{1}$$

$$= \frac{4 - 3.7}{4} \times \frac{100}{1} = \frac{0.3}{4} \times \frac{100}{1} = 7.5\%$$

Sample GK1 wet length = 4 inches

Dry length = 3.7

$$\% \text{ shrinakge} = \frac{wet\ lenght - dry}{wet\ lenght} \times \frac{100}{1}$$

$$= \frac{4 - 3.7}{4} \times \frac{100}{1} = \frac{0.3}{4} \times \frac{100}{1} = 7.5\%$$

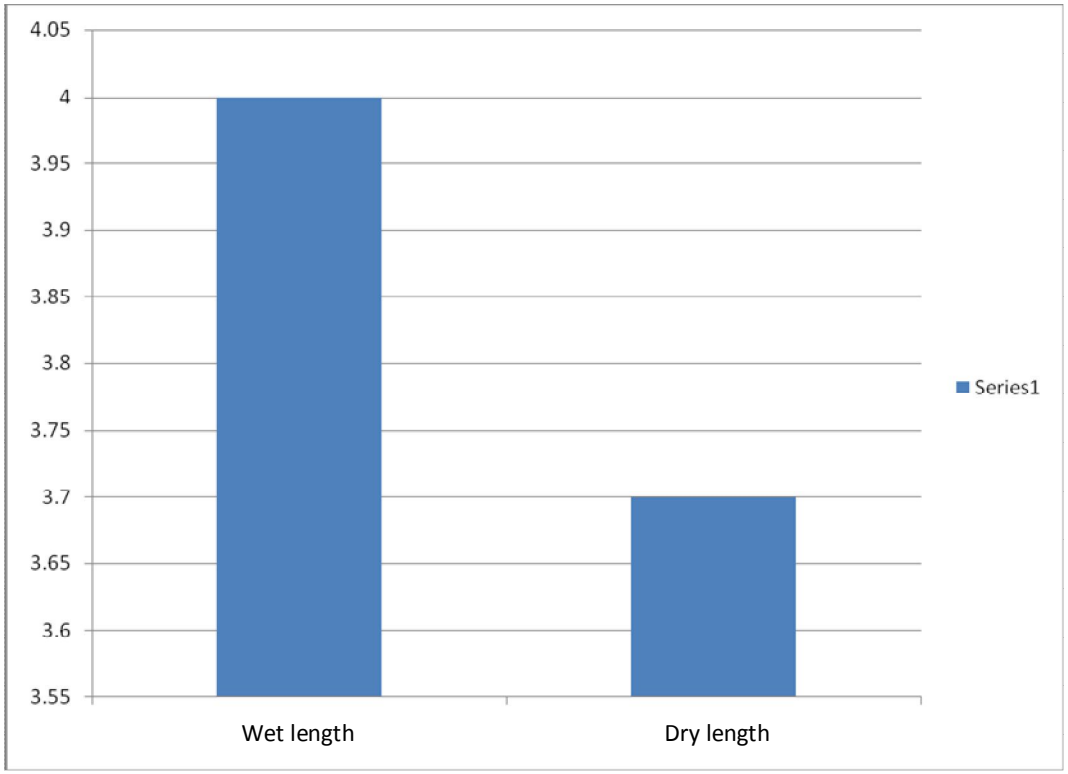


Figure 3.5: GK 1 Dry Shrinkage Test

Graph Representing Wet and Dry Samples from Batches Granite and Kaolin 1

Sample GK2 Wet length = 4 inches

Dry length = 3.8

$$\% \text{ shrinakge} = \frac{wet\ lenght - dry}{wet\ lenght} \times \frac{100}{1}$$

$$= \frac{4 - 3.8}{4} \times \frac{100}{1} = \frac{0.2}{4} \times \frac{100}{1} = 5\%$$

Sample GK2 Wet length = 4 inches

Dry length = 3.8

$$\% \text{ shrinakge} = \frac{wet\ lenght - dry}{wet\ lenght} \times \frac{100}{1}$$

$$= \frac{4 - 3.8}{4} \times \frac{100}{1} = \frac{0.2}{4} \times \frac{100}{1} = 5\%$$

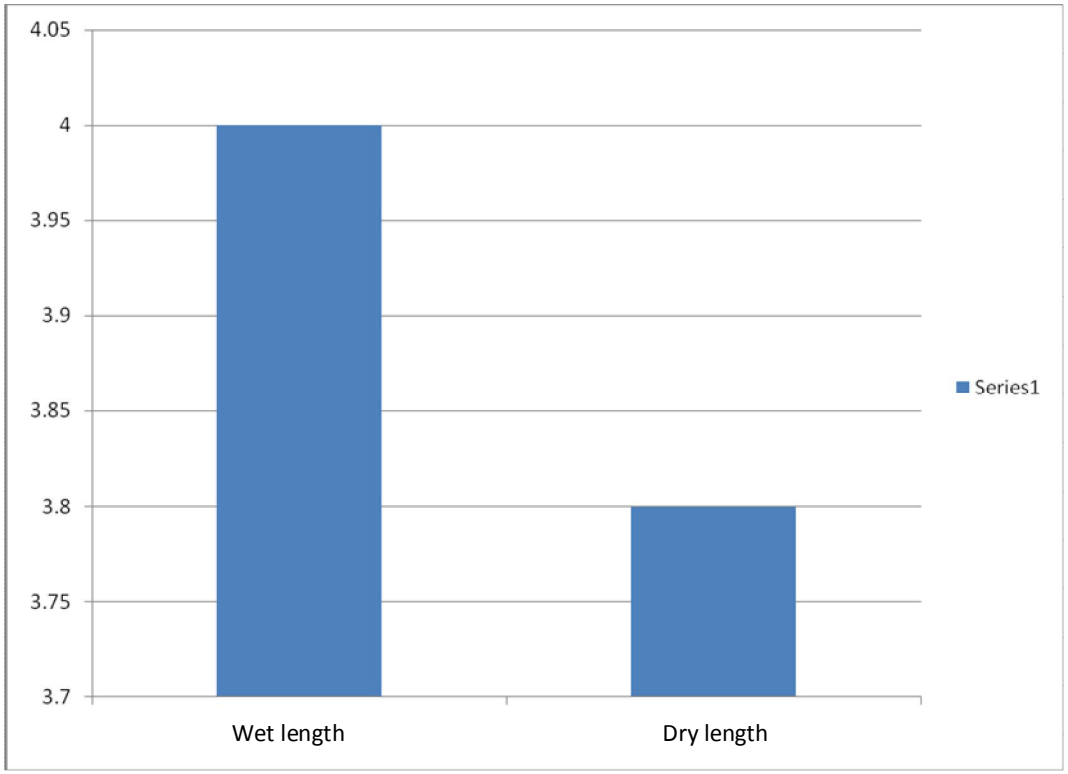


Figure 3.6: GK 2 Dry Shrinkage Test

Graph Representing Samples from the base material/Kaolin group 2

Fired Shrinkage Test

Samples GB1 wet length = 4 inches

Fired length = 3.7

$$\% \text{ shrinakge} = \frac{wet\ lenght - dry}{wet\ lenght} \times \frac{100}{1}$$

$$= \frac{4 - 3.7}{4} \times \frac{100}{1} = \frac{0.3}{4} \times \frac{100}{1} = 7.5\%$$

Samples GB1 wet length = 4 inches

Fired length = 3.7

$$\% \text{ shrinakge} = \frac{wet\ lenght - dry}{wet\ lenght} \times \frac{100}{1}$$

$$= \frac{4 - 3.7}{4} \times \frac{100}{1} = \frac{0.3}{4} \times \frac{100}{1} = 7.5\%$$

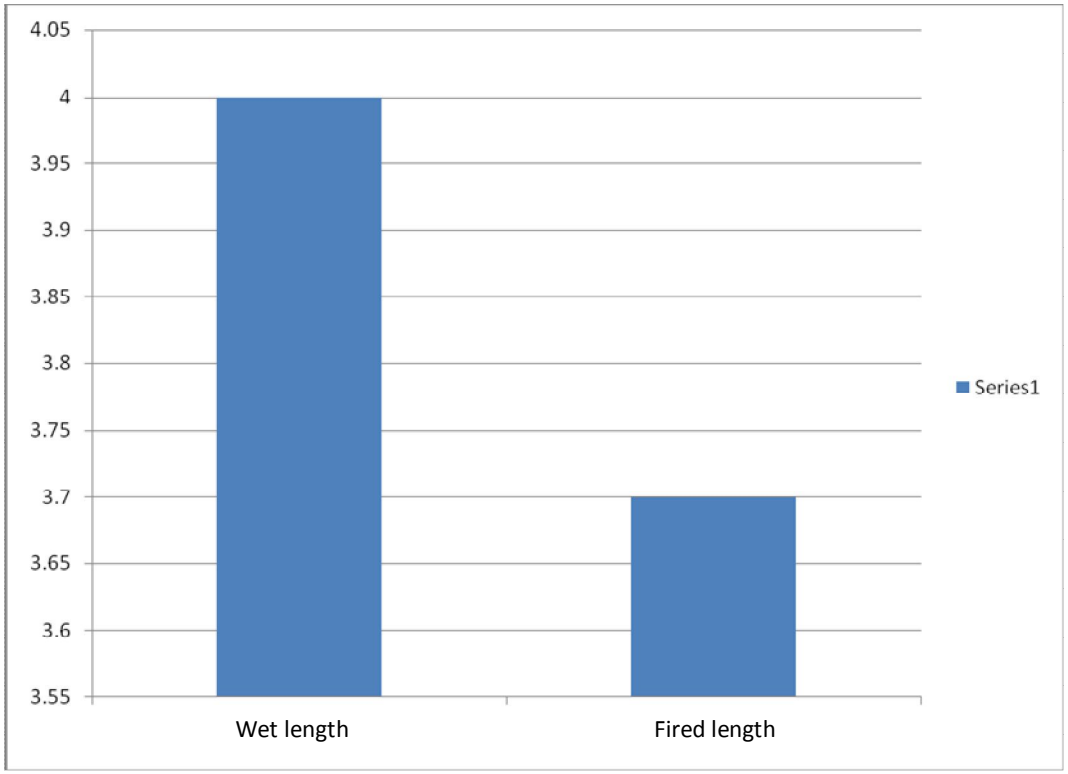


Figure 3.7: GB 1 Fired Shrinkage Test

Samples from the Base material/Ball Clay Group 1

Samples GB2 wet length = 4 inches

Fired length = 3.8

$$\%\ \text{shrinakge} = \frac{wet\ lenght - dry}{wet\ lenght} \times \frac{100}{1}$$

$$= \frac{4 - 3.8}{4} \times \frac{100}{1} = \frac{0.2}{4} \times \frac{100}{1} = 5\%$$

Samples GB2 wet length = 4 inches

Fired length = 3.8

$$\%\ \text{shrinakge} = \frac{wet\ lenght - dry}{wet\ lenght} \times \frac{100}{1}$$

$$= \frac{4 - 3.8}{4} \times \frac{100}{1} = \frac{0.2}{4} \times \frac{100}{1} = 5\%$$

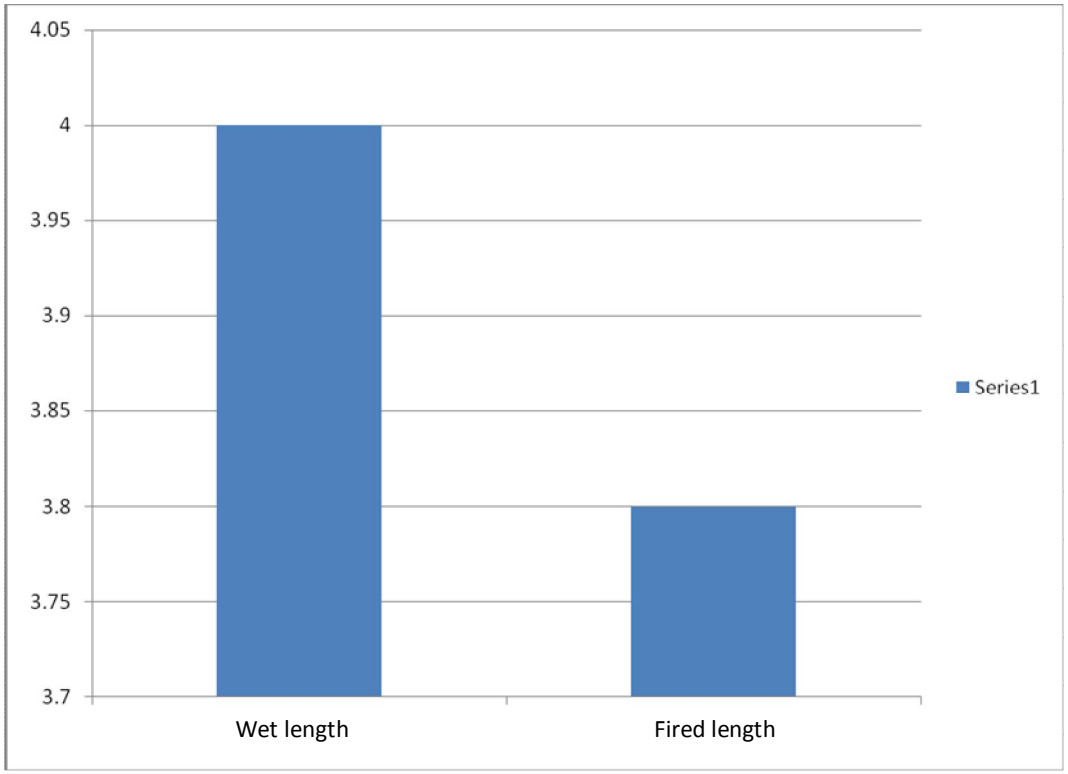


Figure 3.8: GB 2 Fired Shrinkage Test

Samples from the Base Material/Ball Clay Group 2

Samples GK1 Wet Length = 4 inches

Fired length = 3.85

$$\% \text{ shrinakge} = \frac{wet\ lenght - dry}{wet\ lenght} \times \frac{100}{1}$$

$$= \frac{4 - 3.85}{4} \times \frac{100}{1} = \frac{0.15}{4} \times \frac{100}{1} = 3.75\%$$

Samples GK1 Wet Length = 4 inches

Fired length = 3.85

$$\% \text{ shrinakge} = \frac{wet\ lenght - dry}{wet\ lenght} \times \frac{100}{1}$$

$$= \frac{4 - 3.85}{4} \times \frac{100}{1} = \frac{0.15}{4} \times \frac{100}{1} = 3.75\%$$

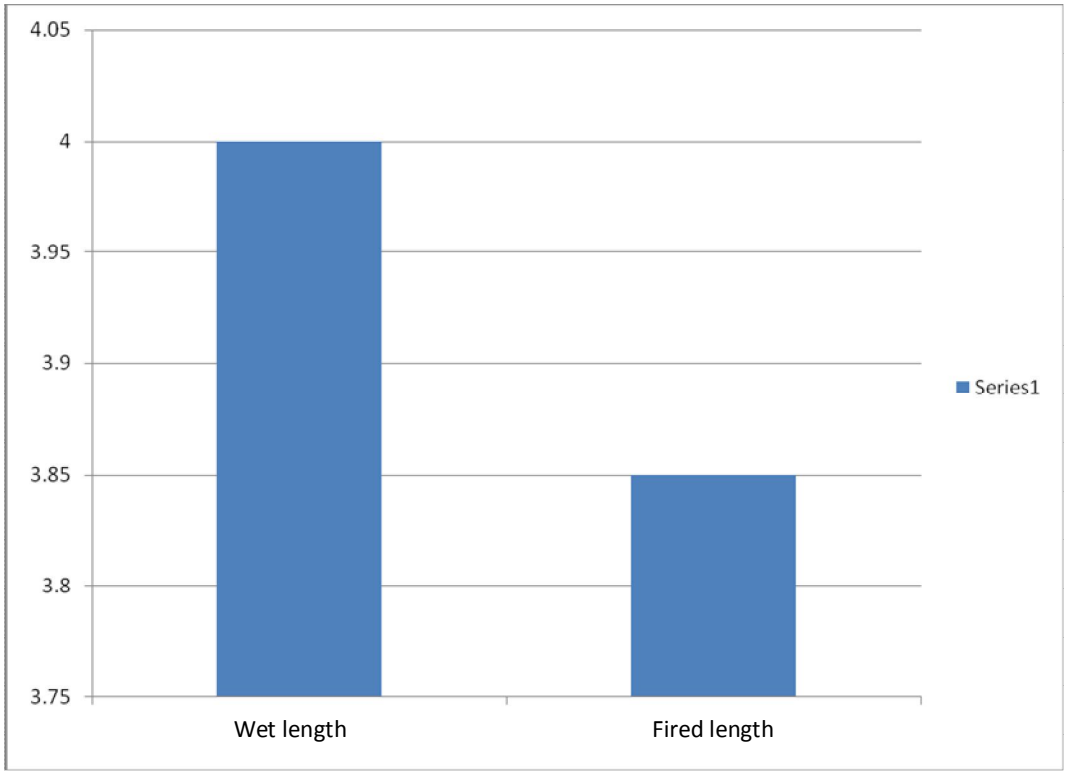


Figure 3.9: GK 1 Fired Shrinkage Test

Fired Samples from the Base Material/Kaolin Group 1

Samples GK2 Wet Length = 4 inches

Fired length = 3.9

$$\% \text{ shrinakge} = \frac{wet\ lenght - dry}{wet\ lenght} \times \frac{100}{1}$$

$$= \frac{4 - 3.9}{4} \times \frac{100}{1} = \frac{0.1}{4} \times \frac{100}{1} = 2.5\%$$

Samples GK2 Wet Length = 4 inches

Fired length = 3.9

$$\% \text{ shrinakge} = \frac{wet\ lenght - dry}{wet\ lenght} \times \frac{100}{1}$$

$$= \frac{4 - 3.9}{4} \times \frac{100}{1} = \frac{0.1}{4} \times \frac{100}{1} = 2.5\%$$

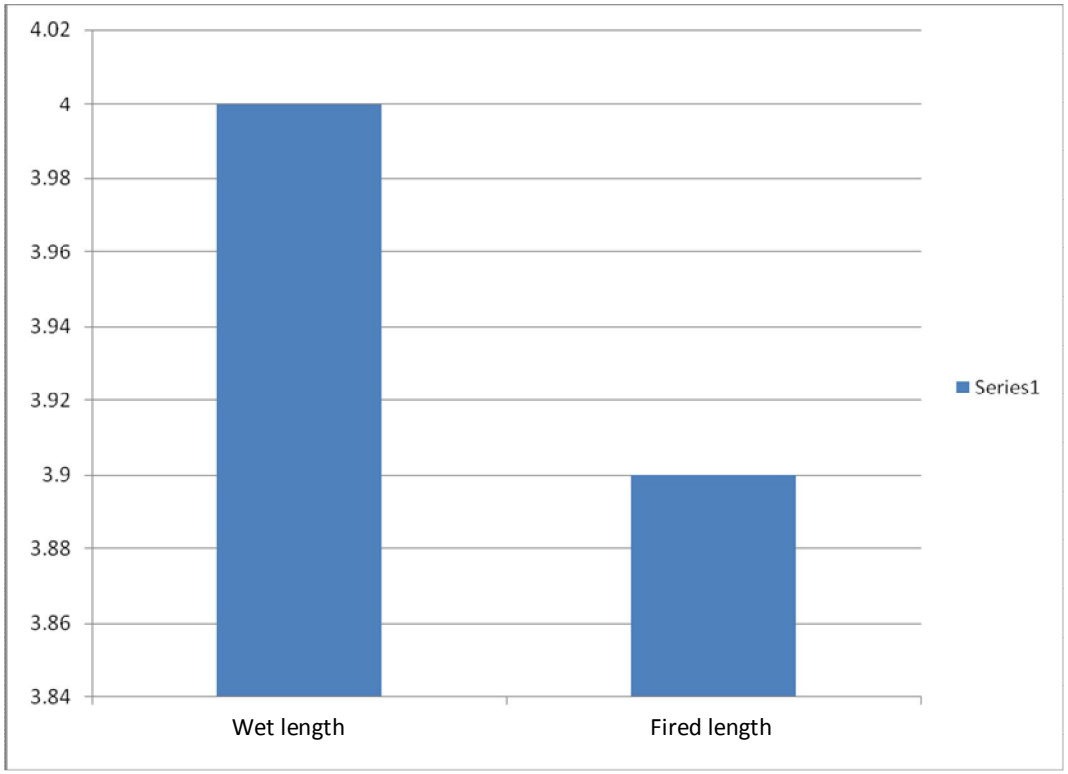


Figure 3.10: GK 2 Fired Shrinkage Test

Fired Samples from Base Material/Kaolin Group 2

Table 3.28: Shrinkage Rate of some Composites

Batch type	Dry Shrinkage	% Shrinkage	Fire Shrinkage	% Shrinkage	Total Shrinkage
GBC1	3.6	10%	3.7	7.5%	7.5%
GBC1	3.6	10%	3.7	7.5%	7.5%
GBC2	3.7	7.5%	3.8	5%	5%
GBC2	3.7	7.5%	3.8	5%	5%
GK1	3.7	7.5%	3.85	3.5%	3.5%
GK1	3.7	7.5%	3.85	3.5%	3.5%
GK2	3.8	5%	3.9	2.5%	2.5%
GK2	3.8	5%	3.9	2.5%	2.5%

Source: Studio Experiment by the researcher.

3.8 Rate of Absorption and Porosity Test

For the formulated body to achieve glaze adhesion, the level of porosity of 5-10% must be determined to ensure that it meets the recommended standard as suggested by Hammer and Hammer (2004). A total of 36 samples were made, 18 were fired to 900^{o}C and the remaining 18 were fired to 1200^{0}C. These were weighed at dry stage, recognized as wd, and recorded. Samples were submerged in water for 5 hours and were later taken out, recognized as ww and the absorption rates were calculated. Below is the calculation in percentage and the table 3.29 to 3.32 highlighting the shrinkage tests at 900 and 1200 respectively, while figure 3.9 to 3.12 also expressed the hours it takes for water of absorption.

Absorption rate= $\frac{ww - wd}{wd} x \frac{100}{1}$ = percentage

= $\frac{ww - wd}{wd} x \frac{100}{1}$ x $\frac{100}{1}$

= $\frac{120.70 - 113.68}{113.68} x \frac{100}{1} = 7.02(6.17\%)$

The absorption rate of GB, 1 is 7.02, representing 6.17%

3.9 Water Absorption Test at 900^0C

Table 3.29: Result of Water Absorption Test at 900^0C

Sample No	**Wt at 900^0C**	**5 hour absorption**	**Absorption at 900^0C**	% Absorption
GBC1	113.68	120.70	7.02	6.17
GBC1	113.68	120.70	7.02	6.17
GBC1	114.07	122.69	8.62	7.56
GBC1	114.07	122.69	8.62	7.56
GBC2	123.88	130.88	7.00	5.65
GBC2	123.88	130.88	7.00	5.65
GBC2	123.88	130.88	7.00	5.65
GBC2	123.88	130.88	7.00	5.65
GBC2	123.88	130.88	7.00	5.65
GK1	123.88	130.90	7.02	5.06
GK1	135.87	140.94	5.07	3.73
GK1	135.87	140.94	5.07	3.73
GK1	135.87	140.94	5.07	3.73
GK2	142.86	146.87	5.01	3.53
GK2	140.88	146.87	5.99	4.25
GK2	140.88	146.87	5.99	4.25
GK2	141.88	146.87	4.99	3.51
GK2	141.88	146.87	4.99	3.51

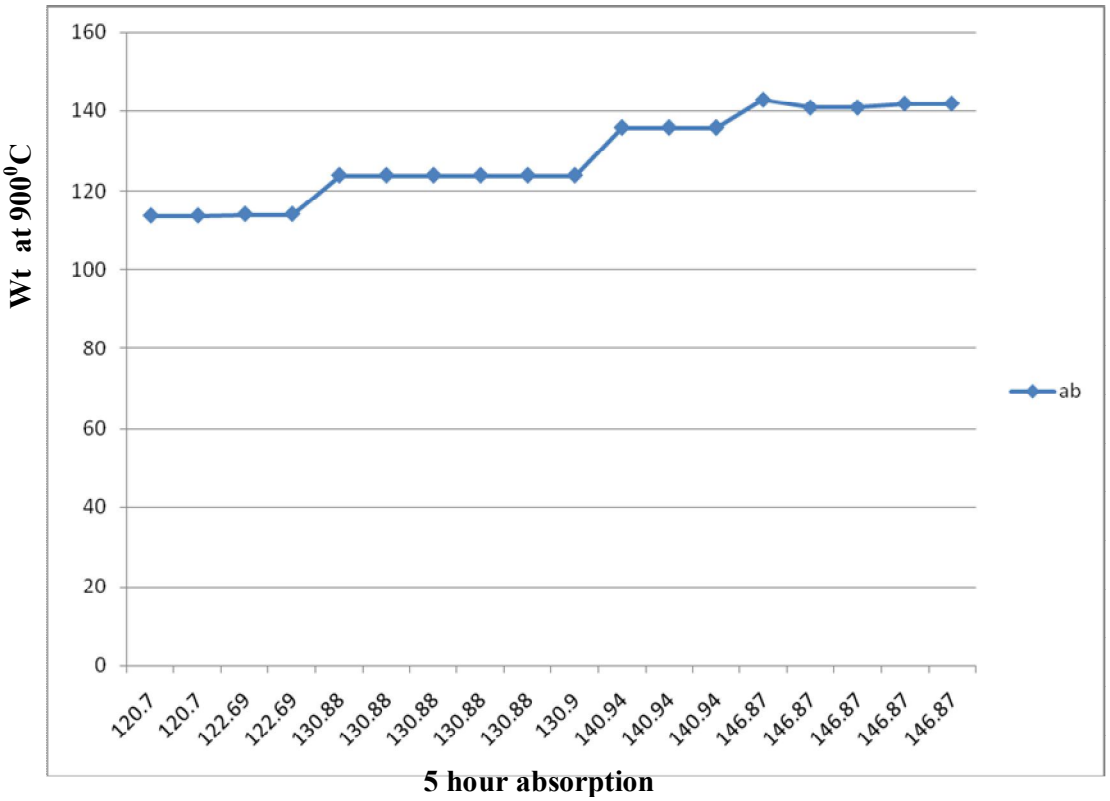


Figure 3.11: 5 hours water absorption test at 900^{0}C

Table 3.30: Result of Water Absorption Rate at 900^0C

Sample No	Wt at 900^0C	24 hour absorption	At 900^0C	% Absorption
GBC1	113.68	139.24	25.56	22.48
GBC1	113.68	139.24	25.55	22.48
GBC1	114.07	140.24	26.17	22.94
GBC1	114.07	140.24	26.17	22.94
GBC2	123.88	150.11	26.22	21.17
GBC2	123.88	150.11	26.22	21.17
GBC2	123.88	150.11	26.23	21.17
GBC2	123.88	150.11	26.22	21.17
GBC2	123.88	150.11	26.23	21.17
GK1	123.88	150.11	26.23	21.17
GK1	135.87	159.87	24.01	17.65
GK1	135.87	159.86	24.00	17.66
GK1	135.87	159.86	24.00	17.66
GK2	141.86	167.87	26.01	18.33
GK2	140.88	166.51	25.63	18.17
GK2	140.88	166.51	25.63	18.19
GK2	141.88	167.87	25.99	18.32
GK2	141.88	167.87	25.99	18.32

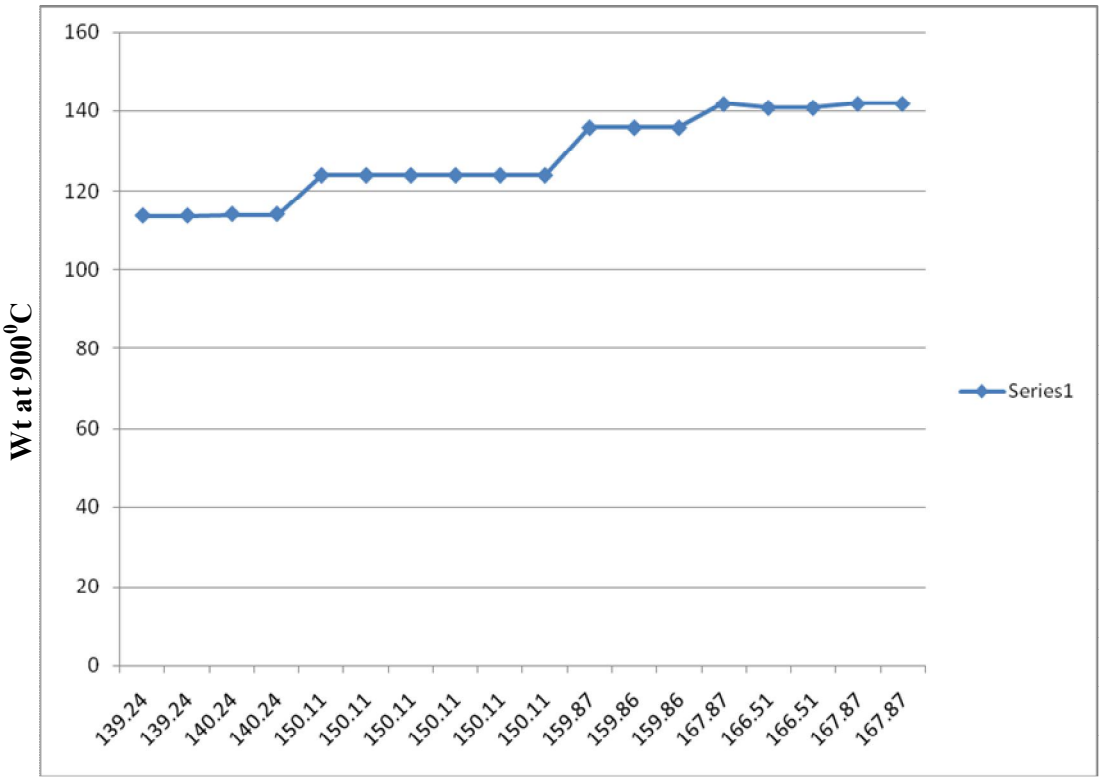


Figure 3.12: 24 hours water absorption test at 900^{0}C

Table 3.31: Result of Water Absorption Test at 1200^0C

Sample No	Wt at 1200^0C	5 hour absorption	Absorption at 1200^0C	% Absorption
GBC1	97.07	97.07	0.00	0
GBC1	97.07	97.07	0.00	0
GBC1	98.18	98.18	0.00	0
GBC1	98.18	98.18	0.00	0
GBC2	98.30	98.30	0.00	0
GBC2	98.30	98.30	0.00	0
GBC2	98.30	98.30	0.00	0
GBC2	98.30	98.30	0.00	0
GBC2	98.30	98.30	0.00	0
GK1	92.07	95.09	3.02	3.28
GK1	92.07	95.09	3.02	3.28
GK1	92.30	95.09	2.79	3.02
GK1	92.30	95.09	2.79	3.02
GK2	93.07	96.07	3.00	3.22
GK2	93.07	96.07	3.00	3.22
GK2	93.07	96.07	3.00	3.22
GK2	93.07	96.07	3.00	3.22
GK2	93.07	96.07	3.00	3.22

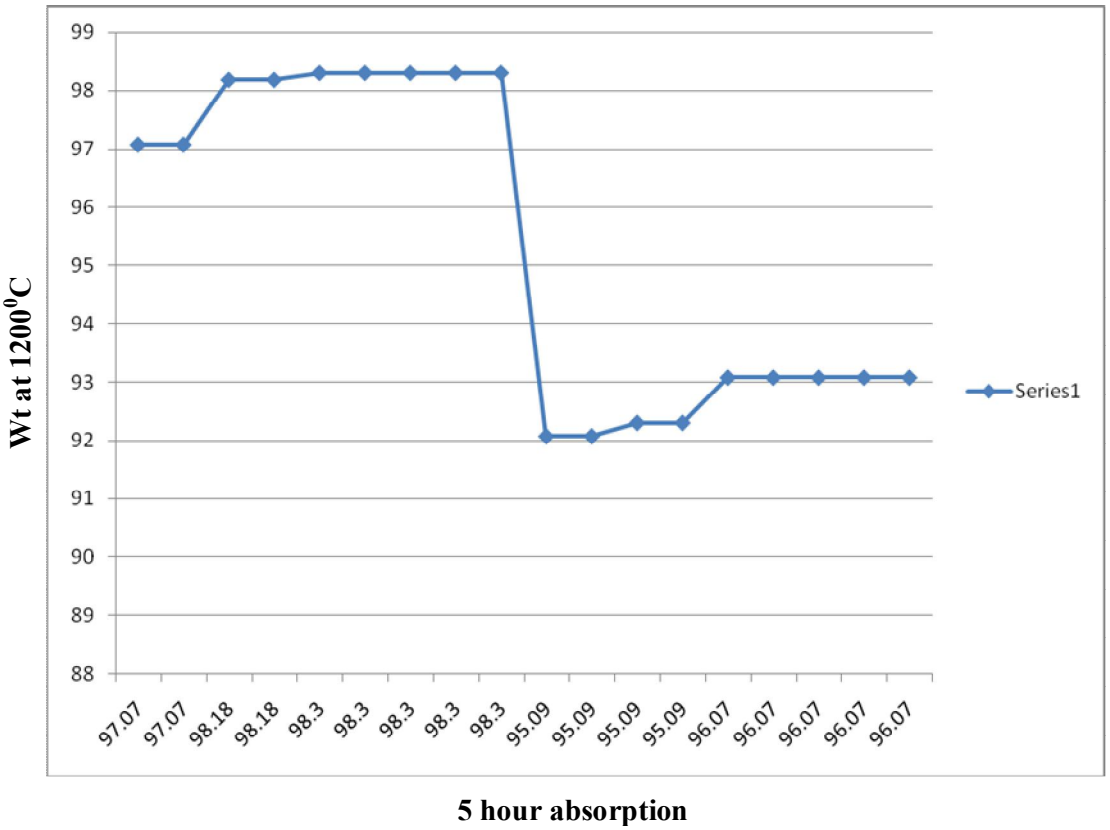


Figure 3.13: 5 hours water absorption test at 1200^{0}C

Table 3.32: Result of Water Absorption Test at 1200^0C

Sample No	Wt at 1200^0C	24 hour absorption	Absorption at 1200^0C	% Absorption
GBC1	97.07	97.07	0.00	0
GBC1	97.07	97.07	0.00	0
GBC1	98.18	98.18	0.00	0
GBC1	98.18	98.18	0.00	0
GBC2	98.30	98.30	0.00	0
GBC2	98.30	98.30	0.00	0
GBC2	98.30	98.30	0.00	0
GBC2	98.30	98.30	0.00	0
GBC2	98.30	98.30	0.00	0
GK1	92.07	95.09	3.02	3.28
GK1	92.07	95.09	3.02	3.28
GK1	92.30	95.09	2.79	3.02
GK1	92.30	95.09	2.79	3.02
GK2	93.07	96.07	3.00	3.22
GK2	93.07	96.07	3.00	3.22
GK2	93.07	96.07	3.00	3.22
GK2	93.07	96.07	3.00	3.22
GK2	93.07	96.07	3.00	3.22

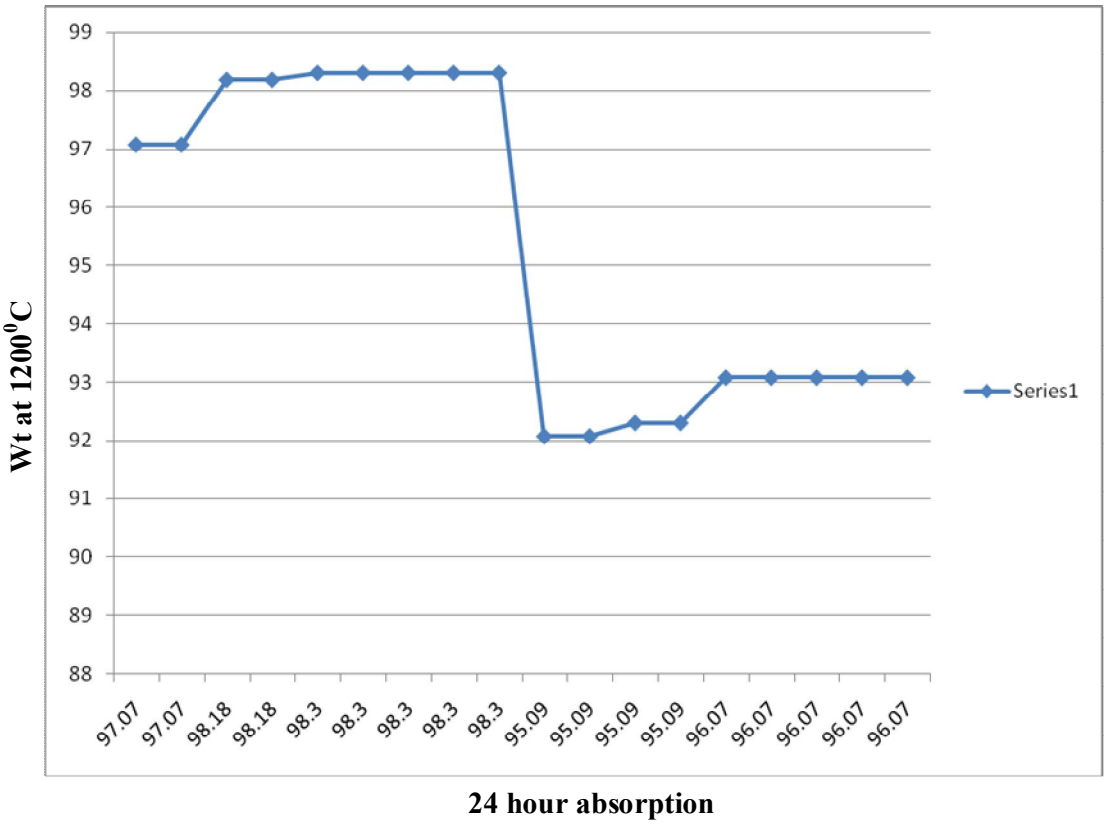


Figure 3.14: 24 hours water absorption test at 1200^{0}C

CHAPTER FOUR

4.0 Results and Findings

In attempting to solve the problem of this study which involves the use of granite waste in developing ceramic bodies, this research employed several steps which involved collection of materials, analysis of these materials, formulation of bodies, production of sample wares and firing. This chapter is a documentation of the results of analysis and studio experiments conducted in the cause of this study and the findings that were made.

4.1 Result of the Analysis of Samples

The chemical analysis was conducted to find out the chemical composition of sample mineral so as to confirm their presence and values. The chemical composition of granite showed the dominance of alumina, silica and feldspar. Alumina serves as a stabilizer, silica acts as glass formers while feldspar represents the flux. These minerals were equally found in both kaolin and ball clay. This explains the reason why they are compatible in the formulation of those bodies under investigation.

4.2 Result of Body Formulation

Many defects could be associated with ceramic production. Some of these faults are as a result of poor body formulation. There are different materials used in compounding a body. They are classified as clays, fluxes, hardeners and openers. In some clay, these materials can be undesirable and should be removed during body preparation. Some may be more desirable and should be added during body preparation. This art when not well mastered could create a number of faults such as cracks during drying and firing, distortion, blisters or bloating and a host of others. The

formulated body classified as GBC l and 4 and GK 1 and 4 were devoid of these faults and could be used to produce a wide range of ceramic products such as flower vases, ceramic sculptures and lamp bases .The bodies produced show three distinct colours which influence glaze colouration. They are dark brown, buff red and cream.

4.3 Result of Shrinkage Test

The shrinkage test conducted on the samples showed shrinkage rates of 2.5-7% which falls within the acceptable range as recommended by Nelson 1960. The compositions that combined granite and Kaolin shrunk less compared to the bodies that combined granite and ball clay. The reason for this variation in percentage shrinkage is that kaolin characteristically is defined by its low plasticity and large particle size. These two attributes promote low shrinkage. Secondly, ball clay is known for its high plasticity and fine particle size, these factors account for the shrinkage and quick sinterability.

4.4 Result of Apparent Porosity and Water Absorption

Granite, ball clay and kaolin combined at various percentages were fired to 900°C. At 900°C, large percentage of silicates and feldsparthoids began to melt and fill the pores created by the expelled water in the body. Theoretically, this occurs between temperatures 700°C-900°C. At 900°C the sintering is not complete leaving a good amount of porosity that could be good enough to promote glaze intake in the body. The result however showed a very high absorption rate of between 5.07-8.62 %, which is far greater than what is expected to be the normal range of 3-5 % in stone ware bodies. This is partly due to the grain size of granite dust valued at 125 microns and the presence of kaolin, which are both non-plastic materials, short in plasticity and large in

particle size. The presence of these materials created interstitial spaces between the clay and would only break down effectively at temperatures higher than 1200°C. This accounts for the high porosity observed in these bodies.

4.5 Result of Ware Hardness and Handling Property Tests

The products that came from the compounded bodies were hard enough to withstand the pressure of handling during drying, glazing and firing operations. One of the most fascinating discoveries in this research is the fast drying rate and no cracks experienced when these products were exposed under the sun within six hours. However, there was no other scientific explanation to this phenomenon except to attribute this behaviour to the character of granite dust incorporated in the body that was compounded.

4.6 Result of Warpage Test

Standing wares were produced from the formulated bodies and fired to 900°C and 1200°C to ascertain the degree of warpage. No sign of warpage was noticed in any of the wares which showed the stability of forms to be produced with these bodies.

4.7 Result of Sintering

Composites were fired to 900^0C and 1200^0C. At 900^0C little amount of sintering took place, but was not significant enough to cause fusion. However at 1200^0C, the bodies sintered and completely fused together. Result of water absorption showed that bodies that were compounded with ball clay and granite fused completely and could not absorb 1% of water, while those compounded with kaolin and granite still absorbed 2-3% of water after 5-24 hour absorption test as recommended by

Garkida, (ibid) This showed that sintering process and fusion was not complete in these bodies and could still be fired at higher temperatures to achieve complete sinterability and fusion.

Result from experiments with bodies that combined granite and ball clay in the ratio of 8:2, 7:3 all fused and melted away at the firing temperature of 1200^0C. This explains why granite was once described by Ahuwan (2012, a personal discourse) as "fugitives". Such a material requires a greater amount of alumina in the clay to stabilize it, and a good amount of silica to harden it.

4.8 Result of Slip Casting

It was earlier stated in this research that because of the non-plastic nature of these bodies, objects produced from it could only be produced through the casting method. The result of this procedure showed that the bodies responded positively to every cast made from the plaster moulds. In fact, because of the low water content and the low plasticity and large particle size that characterized these bodies, casting was very fast and 5-6 sets of productions were done in less than two hours and yet the moulds were not saturated.

4.9. Result of Glaze Adhesion and Firing Test

According to Brian (1987) it is essential that a glaze must be compatible with a clay body and be able to bond together if the body must be described as a successful stone ware body. Both glaze and body must fit to one another otherwise defects such as crazing could occur. The experiment showed that the bodies when fired to 900^0C were able to take sufficient glaze and the glaze equally made from granite material was compatible with the body.

4.9.1 Result of Plasticity Test

The bodies formulated were less plastic compared with bodies meant for throwing and hand building. As a consequence, they could not be recommended for throwing and hand construction. The plasticity index as discovered during physical test of bodies was at best average in bodies that were compounded with 60:40 ratios of clay and granite but as low as 40 percent in bodies with 60:40 granite/kaolin.

4.9.2 Findings

Based on the result already stated the following findings were made. These are:

1. Granite sawing waste in combination with ball clay and kaolin produced a number of clay bodies that could be adopted for the production of ceramic wares.
2. Granite sawing waste could be used to temper natural clays in order to overcome some short comings inherent in these clays that could not allow it to be used solely as bodies in ceramic production.
3. The utilization of granite sawing waste introduces another avenue through which these waste could be rechanneled in order to reduce the negative impact it could have on the environment.
4. Due to its low plastic index, it was observed that the handling properties required, that is, ware hardness at green and fired stage and drying strength could not meet the requirement for hand construction and throwing. However, they are good enough for casting so long as one exercises a good degree of carefulness.

5. The shrinkage rate obtained in these bodies which stood at an average of 5-7% was quite good and met the required standard recommended Nelson (1964), for stoneware bodies.
6. The values obtained by the apparent porosity test were quite high compared to the recommended values of 5-10% by Hamer and Hamer(ibid).This constituted a major problem during glaze operation, as wares absorbed a great quantity of glaze when dipped into the glazes. This however can be corrected by making the glaze consistency lighter and also dampening the ware with soft wet sponge or simply dipping the ware in water and allowing it absorb water before applying glazes. Another way out of this is to simply use a spray gun to introduce glaze on the surface of the ware.
7. Vitrification required for a workable body was attained at a temperature much lower than the stone ware bodies one is familiar with. Most of the bodies derived from the combination of granite and ball clay started sintering at 900^0C and at 1200^0C, the sintering process and complete fusion was obtained. Those with greater amount of granite could be termed "self glazed body" a term coined by Conrad (1979).This is because some of these bodies melted and shined on their own without glaze application.
8. Because of the low plasticity and large particle size of the body constituents, little or no warpage was experienced.
9. The bodies formulated could absorb glaze at bisque temperature. Both body and glaze were compatible. No major glaze fault and body defects were observed. However, a glaze batch that was finely ground to the grain size of 180 microns created a crazing effect when it was thickly applied.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary and Conclusion

It has become obvious, measuring by the series of experiments carried out that, granite waste could be incorporated into clays for the formulation of clay bodies in ceramics.

The experiment utilized granite wastes in combination with clay at various ratios using the triaxial blend technique. Test bars were first, produced to test the workability of these bodies. This was followed by the production of ceramic wares through casting to determine the level of its workability. The experiments were successful, but not without some difficulties and discoveries which are reported in the findings.

By this experiment therefore, it can be concluded that, huge granite waste that are generated around quarry sites could be adopted as a secondary raw material in the production of ceramics. This could save the environment and plants from degradation and also prevent several health hazards that workers in these firms are exposed to.

The chemical and property test carried out established the presence of all the desired elements necessary for body formulation and both granite and the clay additives were compatible in their chemical nature and as such no conflict was recorded in their reaction to one another.

The wares produced conformed to all required functional standard and attributes such as tensile strength, non deformity and warpage. No defects such as bloating, cracks and blisters were recorded. The apparent porosity yield the required values and as such was able to absorb sufficient glaze which introduced sufficient inpermeability, shine and the aesthetic features that one is looking for.

5.2 Recommendations

5.3 General Recommendations

Ceramics as practiced today in our studios and taught in our institutions is limited in several ways. This is majorly due to the kind of materials used, processes adopted in processing such materials, the limitation of wares produced in terms of application, the technique and technology employed in making them, coupled with the untrained man power. There are so many factors or variables involved in the manufacture of modern ceramics suitable for a wide range of applications in science, engineering and art. This cannot be achieved without modern research laboratories and equipment as well as trained man power.

The federal government in her effort to promote ceramic production set up the Raw Material Research and Development Council (RMRDC), which engaged in the development of ceramics raw materials. This establishment assisted in the supply of local raw materials needed in Nigerian studios and other ceramic industries. However, this centre is now a shadow of its former self. The need to install modern equipment as well as upgrade the existing research facilities capable of analyzing various ceramic materials and products to cope with modern trends in material science development is long overdue. A situation where ceramic researchers carry samples of their materials and products to other research institutes, begging for analysis is not a healthy development for this field of study.

In Nigeria, a lot of solid minerals have been identified and earmarked for mining in an effort to re-diversify the revenue base of the economy currently dominated by the oil sector. Presently, a few are been mined for domestic consumption and for export. This means that a lot of mining waste is been generated that is already posing a serious threat to the ecosystem. Granite and marble are been mined, quarried and

processed for use in creating pavements, cladding of walls, back splashes in kitchen, cladding of fire places and even garden landscaping.

The study recommends an innovative strategy that must be geared towards effective management of the mining waste been generated by these plants. The innovation here being proposed lies in the fact that those mineral waste that were to end up in landfills or washed away by rains ends up as house hold or green building products. The study specifically recommends that each mining company should establish a waste management plant that collects, recycle and re-use waste generated by it.

Currently the responsibility of managing and regulating waste management policies is delegated to federal and state government. The research recommends that the responsibility of managing waste be completely delegated to private companies for effective management of the waste. If they are nonexistent at the moment in most states, government should woo investors in this area from other countries just as it does in other areas of the economy.

Furthermore, public enlightenment campaigns should be intensified to galvanize interest and cooperation from material suppliers, manufacturers, retailers and consumers, to share responsibility for reducing mining waste. Beginning with design, products can be made and used in ways that conserve materials and foster re-use. Important opportunities for waste reduction abound in product design and development, these should be exploited.

5.4 Recommendations for Further Studies

The research suggests the following as recommended areas for further studies, these are:

1. That the intentional tempering of clay which used to be an ancient art should be revisited in ceramic studio practice so as to achieve product differentiation by the creation of special effects and other alternative products which, in the market setup could be an impetus or stimulus for more sales. Granite waste could be used to enhance the mechanical and technological properties of clay for the production of structural products such as balusters, inter-locking tiles and other building products.
2. Secondly, several ornament or gem stone exist in the country apart from granite, quartz and marble, traditionally known as emerging materials in the development of products. The gem stones include topaz, Barnet, monazite, bronze, sapphire, aquamarine, amethyst and diamond. According to the (Central Bank of Nigeria Annual Report, 2005), these are being considered for exploration and some are already being mined and processed by local miners for various applications such as jewellery and other decorative purposes. Most of these stones contain natural pigments that can be extracted and introduced into glazes as colorants and body stains. Or better still, they could be used as tempering materials for the creation of special effect in the practice of mix-media approach in ceramics. The study further recommends that these materials be adopted to produce “self glazed" bodies as this will eliminate several production processes, save cost and achieve a new product outlook or special effect.
3. Granite waste could be used as alternative material to feldspar (which could be soda, potash or nepheline) in establishing a transparent base glaze for the purpose of achieving colour blending in ceramic glazes and for testing colouring materials. After the formulation of a base glaze, two or three materials

are mixed at various proportions alongside a triangular or rectangular table. By this triaxial or quadrilateral blend, sixteen to twenty four results of which at least, three to four could be useful at the required temperature and colour effect.

Similarly, some potters add colouring oxides as part of the molecular formula of a glaze batch. However, the normal and recommended practice such as recommended by Fraser (1973), is to count the base glaze as 100% and then add an appropriate percentage of colours. A glaze could therefore be calculated as 100% plus 1or 2 parts of oxides. Granite waste is thus recommended as a chief material in the formulation of base glazes for the testing of colouring materials and colour blending in ceramics.

REFERENCES

Acchar, W., Vieira, A.F., and Segadaes, A.M. (2006) "Using Ornamental Stone Cutting Rejects as Raw Materials for Red Clay Ceramic Products" Journal of Material Science and Engineering,Taiwan. Vol.43. Pp 606 - 610.

Ahuwan, A.M. (1997) "Determination of Physical and Chemical Properties of Clay Samples in Bauchi State, Suspected to be Kaolin". Environ - Journal of Environmental- Studies, Faculty of Environmental Design, Ahmadu Bello University, Zaria. Vol.1. No.1 Pp. 29 - 35.

Ahuwan, A.M. Opoku, E.V. and Garkida A.D. "Recycling Waste Window Glasses in Ceramics Glazes as Alternative to Feldspar". Ashakwu Journal of Ceramics.Ceramics Association of Nigeria, Zaria. Vol. 1. No 2. 2004. Pp. 39 - 42.

Ahuwan, A.M. Garkida, A.D. and Gonah C'M .(2001)"Exploring the Usage of Kankara Kaolin in the Glass Industry". JOSCILT. International Journal of Science Laboratory Technology.Glass Technology,Department of Industrial Design Ahmadu Bello University,Zaria. 2001. Vol. 1. No 1. Pp. 59 - 62.

Alkali, V. (1995) "Development of Ceramics Proto-type Gas Stove Using Locally Available Resources". Unpublished M.A. Thesis. Department of Industrial Design. Ahmadu Bello University, Zaria.

Alkali,V.C. Garkida,A.D. Ahuwan A.M.(2006)"Utilization of Granite Sawing Waste in Ceramic Composites."Joscilt International Journal of Science Laboratory Technology.Glass Technology,Department of Industrial Design,Ahmadu Bello University Zaria,Nigeria.Vol.6 pp55-58.

Akinbogun, T.L. (2003) "Chronicle of the Development of Ceramics Products from Monolithic Earthen Ware to High Technology Ceramics" Ashakwu Journal of Ceramics.Department of Industrial Design Ahmadu Bello University,Zaria. Vol. 1. No.1 pp. 44 - 49.

Bovea, M.D., and Powell, T .c. (2006) "The Role Played by Environmental Factors in the Integration of a Transfer Station in a Municipal Solid Waste Management System".Science Digest.Volume 27 No 4. Elsevier Ltd.london.pp545

Bray, C. (2000) "Ceramics and Glass, A Basic Technology" Society of Glass Technology Don Valley House Savile Street, East Sheffield U.K.

Brian S. (1987) “Glazes from Alafind Sources a Working Hand Book for potters”. A & C Black London University of Pennsylvania Press, Philadelphia.

Cooper, E. and Lewenstein, E. (1988) "Clays and Glazes" Billing and Song Limited Worcester, U.K.

Conrad, J.W. (1979) “Contemporary Ceramic Techniques. Prentice Hall Inc. Englewood
Cliffs. New York.

Conrad, J.W. (1980) "Contemporary Ceramic Formulas" Macmillan Publishers Co. Inc. New York.

Datiri, Y.C. (2007)"Sampling and Testing Clay from Gakwo, Plateau State for Whiteware Ceramic Production" Ashakwu. Journal of Ceramics, Ceramics Association of Nigeria, Zaria.Vol. 4. No.1. pp. 47 - 51.

Dijkema, G.P.J. Reuter, M.A. and Verhoef, E.V. (2000) "A New paradigm for Waste Management". Jaffallan Magazine. Elsevier Science Ltd. Netherlands.

Duke, P. (2009) Recommendations on Best Practices in Waste Exploration “Natural Stone Council (NSC) Crestwood Drive Hollis, New Hamsphire.

Dino, G.A, Fornaro, M. and Trentin, A. (2012) “Quarry Waste Chances of a Possible Economic and Environmental Valorisation of the Montorfano and Baveno Granite Diposal Sites”. Hindawi Publishing Corporation. Journal of Geological Research,Torino,Italy.Volume 20/12,pp11.

Fraser, H. (1973) Glazes for the Craft Potter. Sir Isaac Pitman and Sons Ltd. 39 Parkar Street, Kingsway, London. pp.104.

Garkida, A.D. (2006) "Glass Recycling in Waste Management". An unpublished Ph.D Dissertation Department of Industrial Design. Ahmadu Bello University, Zaria.

Grebanier, J. (1975) "Chinese Stoneware Glazes" Watson-Guptill Publication. University of Michigan.

Gukas, H. 1986 "A Feasibility Study for Formulating some Porcelain Bodies from Local Raw Materials in Kaduna State.' Unpublished M.A.Thesis Ahmadu Bello University, Zaria. Nigeria.

Hotza, D., Acchar, W. and Vieira, F.A. (2006) "Effects of Marble and Granite Sludge in Clay Materials".Journal of Material Science and Engineering A,Volume 419 issue 1-2 pp306-309.

Hamer, J. and Frank, (2004) “The potters Dictionary of Materials and Technology” And C Block. London University of Pennsylvania Press, Philadelphia.Pp 9-11,275

Kofoworola, O.F. (2006) "Recovery and Recycling Practices in Municipal Solid Waste Management in Lagos, Nigeria". Waste Management. Volume27 No 9 1143.National Library of Medicine,8600 Rockville Pike Bethesda MD 20894 USA.pp1139-1143

Kilikoglou, (1994) “Toughening of Ceramic Earthenware by Quartz Inclusion”. An Ancient Art Revisited”. Elsevier science Ltd. Institute of Material Science NCSR Great Britain.

Limbachiya, M.C, (2006) "Chemical Mineralogy Characterization of Coarse Recycled Aggregate" Waste Management, Volume 27 No2. National Library of Medicine.8600 Rockville Pike Bethesda MD.20894.USA pp201-8

Lipsett, CH. (1951) "Industrial Waste Their Conservation and Utilization". The Atlas Publishing Co. Inc. New York Pp. 1 - 3.

Licio, P. 2002) “Firing Process” Engineering materials Hand Book Volume 4: pp 255: Printed in the UN U.S.A.

Mangels, J.A. and Messing, G.L. (1984) "Forming of Ceramics" American Ceramics Society Inc. Columbus Ohio. pp 58.

Manning, D.A.C (1995) “Industrial Minerals” Chapman and Hall, London, Glasgow, New York. pp 35-60.

Marabini, A.M. Plesia, P. Maccari, D. Burragato, F. and Pelino, M. (1998) "New Materials from Industrial and Minning Wastes. Glass-Ceramics and Glass and Rock-wool Fibre". International Journal of Mineral Processing. Vol. 53 pp. 121 - 134.

Mbahi A.A. (2001) "Research Methodology a Practical Guide to Research in Fine Arts, Applied Arts and Performing Arts". Kamani Production A. H. P. Department. Borno College of Education. Maiduguri, Borno State.

Michelle, M. O. (1995) Engineering Materials Handbook”ASM International Materials information society USA.

Nashville T. (2012) “The Innovative Recycling of Granite Waste into Building Products” PRWEB ebooks, http://www.wastetovalue-stone.com.

Natural Stone Council (NSC) (2009) University of Tennessee Center for Clean Products,USA.

Nelson, G.C (1964) Ceramics, “A Potters Handbook” Holt Rinehart and Wiston Inc. New York.pp 119-149

Neyin, C. Metin, E. and Erozturk, E. (2003) "Solid Waste Management Practices and Review of Recovery and Rycycling Operations." Packaging and Waste Recovery Trust Magazine,Turkey. volume 23 No 5 pp 425.

Opoku,E.V. (2007)Contemporary Developments in Ceramic Materials: Development of Local Raw Materials for Ceramic Industry in Nigeria.Ashakwu,Journal of Ceramics.Volume 4 No 2 June 2007 pp 84-88.

Okoli, O.G. (2007) Personal Interview.

Pitcher, W.S. (1993) "The Nature and Origin of Granite". Blackie Academic and Professional Champman and Hall, Wester Chidden Road Bishobriggs, Glasgow London.pp 1-20

Rania, H, Salah, E^2 Safiran, K^3 "Utilization of Marble and Granite Waste in Concrete Bricks" International Conference on Environment and Bioscience. IPCBEE Vol. 21.2011, Lacsit Press. Singapore.pp 286-291

Rincon, J.M. and Hermandez-Crespo, M.S (2001) "New Porcelainised Stoneware Materials Obtained by Recycling of M.S.W. Incineration Fly Ashes and Granite Sawing Residues" Ceramics International Vol. 27, pp 713 - 720.

Singer, F. and Singer, S.S. (1963) Industrial Ceramics. University Press, Cambridge, Great Britain. pp. 59 - 87.

Sullayman, U.A.A (2006) "Utilization of local Raw Materials for the Production of Dense Aluminosilicate Refractory Bricks for Blast. Furnaces Using Semi Dry Pressing Technique an Unpublished Ph.D Dissertation from Ahmadu Bello University, Zaria. pp72-74

Torres, P. Fiernandes, H.R. Tulyaganov, D.U. and Ferreira J.M.F. (2004) "Incorporation of Granite Cutting Sludge in Industrial Porcelain Tile Formulation". Journal of the European Ceramics Society. Vol 24. 3177 - 3188.

Vekinis, G. Kilikoglou, V. and Maniatis, Y. (1994) "Toughening of Ceramic Earthenwares by Qaurtz Inclusion". An ancient Art Revisited" Acta Metallurgical Materials Elsevier Science Ltd. Great Britain Vol. 43. NO.8.

Vieira, CM.F. Monteiro, S.N. and Pecanna, L.A. (2003) "Reformation of Roofing Tiles body with the Addition of Granite Waste from Sawing operation". Journal of the European Ceramic Society Vol. 24 pp 338 - 350

Wensley D. (2002) "Pottery the Essential Manual" The Crowood Press Ramsbury, Marlborough Wiltshire.

Xavier, G.D.C Saboya, F. Maia, PCDA and Aleandre, J. (2011) "Considerations about Degradation of Red Ceramic Material Manufactured with Granite Waste". UENF Department of Civil Engineering. Campos Rio de Jeneiro. Brazil.