DEVELOPMENT OF GROGGED CERAMIC CLAY ROOFING TILES FOR POULTRY HOUSING AS AN ALTERNATIVE TO ZINC SHEETS

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ZARIA, NIGERIA

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FACULTY OF ENVIRONMENTAL DESIGN,

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ZARIA

SUPERVISORY COMMITTEE

PROF U.A.A SULLAYMAN (CHAIRMAN)

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OCTOBER, 2017

DECLARATION

I hereby declare that the dissertation titled "Development of Grogged Ceramic Clay Roofing Tiles for Poultry Housing as an Alternative to Zinc Sheets" has been written by me in the Department of Industrial Design of the Faculty of Environmental Design, Ahmadu Bello University, Zaria under the supervision of Prof. U.A.A Sullayman and Dr. E.V Opoku.

The information derived from the literature has been duly acknowledged in the text and in the list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

Emennaa Chukwuka Ikenna …….. …….

CERTIFICATION

This dissertation titled “Development of Grogged Ceramic Clay Roofing Tiles for Poultry Housing as an Alternative to Zinc Sheets” by Emennaa, Chukwuka Ikenna meets the regulations governing the award of Master of Arts Degree (Industrial Design), of the Ahmadu Bello University, Zaria, Nigeria, and it is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This Dissertation is dedicated to God Almighty for His protection and guidance. It is also dedicated to the memory of my late Brother, Charles "Charry" Emennaa. "You are not forgotten!"

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ABSTRACT

Secondary clay obtained from Bomo, Zaria, Kaduna state was used for this research. Dry samples were fired to produce grog which was crushed and sieved to mesh 20 (840microns). Body composition was formulated with 5, 10, 15, 20 and 25% additions of grog to the clay body with the different samples sintered to three varying temperature ranges of 900oC, 1000oC and 1150oC. Samples fired to the highest temperature sintered properly compared to others and thus had a low water absorption rate of 6%. Results of the Tensile strength and Cold crushing strength tests showed that samples with 5% grog addition fired to 1150oC had the highest values of 3736.82 N/mm2and 285.45 kg/cm2 respectively. These strength property results revealed that samples with low percentages of grog, resisted load better than samples with higher additions. This research indicates a huge prospect of developing grogged clay roofing tiles using locally available clay from the study area.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

The ceramic industry covers a diverse range of compounds and several products that can be manufactured by different methods. In view of this, therefore, this industry presents favourable conditions for the implementation of waste recovery system, thus helping to minimize their adverse impact on the environment (Sultana, S., Ahmed, A. N., Zaman, M. N., Rahman, A. M., Biswas, K. P., and Nandy, K. P., 2014).

Nowadays industrial activities are responsible for the generation of large amounts of solid wastes like ceramic industries, marble and granite industries, paper and textile industries, petroleum refinery, urban waste, ashes, aluminium rich sludge, etc (Vieira and Monteiro, 2007) The ceramic industry covers a diverse range of compounds and several products that can be manufactured by different methods. As a result therefore, this industry presents favourable conditions for the implementation of waste recovery system, thus helping to minimize their adverse impact on the environment (Sultana, *et al*., 2014).

The most used raw materials in the traditional ceramic industries can basically be divided into three categories: plastic components (clays), fluxing components (feldspar) and inert components (quartz and sand). Clay materials used in the red ceramic industry show an extensive range of compositions, which permit the incorporation of a variety of industrial waste materials. Some wastes are very analogous in composition to the actual raw materials used, and often contain materials that can also be helpful in the fabrication of ceramic products. One such waste material is the ceramic rejects, known as grog produced in growing amounts in the ceramic industry.

Reformulated ceramic bricks, in which clay was replaced by grog waste, present lower plasticity that reduces the risk of dimensional defects . According to Vieira *et al*, (2007) grog waste could be used to improve the mechanical properties, workability, and chemical resistance of conventional ceramic bricks.

The earliest form of tiles historically dates back to pre- historic time when the use of clay as a building material was developed independently in several cultures. The first tiles was crude but 600 years ago, people started decorating them by adding pigment for colour and carving low relief designs in to their surfaces (Kashim, I. B., Fadairo, G., and Adedeji, Y. M. D., 2013)

1.2 Statement of the Problem

Leakages in the roofing system, remain one of the main causes of wet litter (mixture of poultry excreta and materials used for bedding) problems in poultry management. Due to several factors which include rusting and corrosion, the widely used zinc roofing sheets over time, deteriorate and develop gaps / holes which let in water. Poultry farmers have suffered huge economic losses as a result of this challenge due to high moisture levels in litter, which is a favourable source for bacterial and viral growth. Other problems associated with wet litter include ammonia emission and deterioration of litter quality, among others (Bharti, 2008). Developing a ceramic based roofing panel using grog and clay to replace zinc sheets will be an advantage due to its durability and resistance to corrosion and rust factors.

1.3 Aim of the Study

This study is aimed at utilizing grog and plastic clay as medium for the production of roofing tiles as a suitable alternative to zinc sheets in poultry management.

1.4 Objectives of the Study

The objectives of the study are to:

i. examine the physical properties of clays such as plasticity, dry and fire shrinkage of the samples for the production of roofing tiles.

ii. examine the elemental properties of the clays by means of x-ray fluorescence spectrophotometer.

iii. design and produce roofing tiles using formulated grogged body

iv. examine the suitability of the tiles by carrying out mechanical property tests which include cold crushing and tensile strength tests of the roofing tile.

1.5 Research Questions

The research questions for this study are as follows:

i. How can the clay samples meet standard requirements of plasticity, dry and fired shrinkage?

ii. How do the chemical properties of clay samples used satisfy the basic requirements of clay for roof tile production?

iii. Are the tile designs made from this research suitable for production of efficient roofing tiles for poultry housing?

iv. How much can the utilization of cold crushing strength and tensile strength assessment provide the strength analysis of the tiles?

1.6 Scope of the Study

This study is limited to the utilization of grog materials sourced from Zaria and environs and also clay obtained and compounded within the study area. This study is confined to field exploration, exploitation, and studio experimentation on these materials for the production of roofing tiles.

1.7 Justification of the Study

Developing an efficient ceramic roofing tile for the poultry industry will promote the harnessing of abundant natural resources, as well as reduce huge economic losses farmers encounter as a result of frequent changes in damaged zinc roofing sheets. Consequently, the cooling effect of using ceramic roofing tiles will revolutionize otherwise difficult/ stressful conditions of poultry farming in hot temperate areas of Nigeria.

Awoniyi, (2003) observes that egg production under the asbestos roof is better than under the metal roof due to reduced adverse temperature effects on the birds which leads to stress conditions that hampers their productivity. It has also been observed that poultry houses emit ammonia gas which forms ammonium hydroxide that rapidly attacks most metal surfaces like zinc roofs. It is expected that the product of this research will provide a better alternative to the existing and commonly used zinc roofing sheets especially in view of harmful effects of asbestos. Though there is evidence of extensive use of grog in ceramic production, there is paucity of information on its use as an additive in clay roofing tile production. This study will bring innovation in the area of grog usage in roof tile design as well as tile production.

1.8 Significance of the Study

The exploitation and processing of ceramic raw materials are enough to influence development and capacity building among the local miners around the communities where they are located. Nigeria had relied solely on her oil wealth at the expense of all other

naturally endowed agricultural and enormous mineral resources that abound in many parts of the country.

This study is significant as it will help create awareness of the possibilities inherent in these materials for the development of ceramic production in the country as a nation. The outcome of the study will propagate a new use for grog which was hitherto dumped as waste and create addition to the inventory on consumable raw materials in Nigeria. The study will open a new vista of opportunities in the utilization of local clays for the production of roofing tiles for residential, educational and commercial buildings in Nigeria.

1.9 Basic Assumptions

The following basic assumptions are drawn

i. That the raw materials for the production of roofing tiles i.e. clay and grog are available in large enough quantities.
ii. That there is a growing demand for alternative roofing tiles in the industry.
iii. That the production of ceramic roofing tiles will introduce variety in the indigenous building industry as a building material
iv. That it will alleviate the current problems faced by poultry farmers by serving as an alternative choice.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 Introduction

The existing literature related to this study are reviewed, with regards to past efforts and existing standards on raw materials, body formulation, etc. all pertaining to ceramic roofing tiles are noted. This section tries to investigate and establish existing areas where studies have been conducted, with a review of all such related and relevant literature, to help contribute to the success of the present study.

2.2 Tile

A tile is a manufactured piece of hard-wearing material, usually made of ceramic, stone, metal, or glass, generally used for covering roofs, floors, walls, showers, or other objects such as tabletops. Alternatively, tiles can be referred to as similar units made from lightweight materials such as perlite, wood, and mineral wool, typically used for wall and ceiling applications. Similarly, a tile is a construction tile or similar object, such as rectangular counters used in playing games. The word tile is derived from the French word *tuile*, which is, in turn, from the Latin word *tegula*, meaning a roof tile composed of fired clay. Örjan, (1990).

Tiles are often used to form wall and floor coverings, and can range from simple square tiles to complex mosaics. Tiles are most often made of ceramic materials typically glazed for internal uses and unglazed for roofing, Other materials are also commonly used, such as glass, cork, concrete and other composite materials, and stone. Tiling stone is typically marble, onyx, granite or slate. Thinner tiles can be used on walls rather than on floors, because the floor requires more durable surfaces that will resist impacts.

2.3 Roof Tiles

Roofing tiles are designed mainly to keep out rain and other adverse weather conditions, and are traditionally made from locally available materials such as terracotta or slate. Modern materials such as concrete and plastics are also used and some clay tiles have a water proof glaze. A large number of shapes (or "profiles") of roof tiles have evolved.

Roof tiles are 'hung' from the framework of a roof by fixing them with nails. The tiles are usually hung in parallel rows, with each row overlapping the row below it to exclude rainwater and to cover the nails that hold the row below. There are also roof tiles for special positions, particularly where the planes of the several pitches meet. They include ridge, hip and valley tiles. These can either be bedded and pointed into cement mortar or mechanically fixed.

Similarly, roof tiling has been used to provide a protective weather envelope to the sides of timber frame buildings. These are hung on laths nailed to wall timbers, with tiles specially moulded to cover corners and jambs (the vertical components that form the sides of a door frame or window frame). Often these tiles are shaped at the exposed end to give a decorative effect. Another form of this is the so-called mathematical tile, which was hung on laths (a thin, narrow strip of straight grained wood used under roof shingles or tiles), nailed and then grouted. This form of tiling gives an imitation of brickwork and was developed to give the appearance of brick (Brunskill, 1970)

2.4 History of Roofing Tiles

Fired roof tiles were found as early as the 3rd millennium BC in the early Helladic house of the tiles in Lerna, Greece. According to Shaw, (1987), debris found at the site contained thousands of terracotta tiles having fallen from the roof.

The earliest finds of roof tiles in archaic Greece are documented from a very restricted area around Corinth, where fired tiles began to replace thatched roofs at two temples of Apollo and Poseidon between 700 and 650 BC. Spreading rapidly, roof tiles were within fifty years in evidence for a large number of sites around the Eastern Mediterranean, including Mainland Greece, Western Asia Minor, and Southern and Central Italy. Early roof tiles showed an S-shape, with the pan and cover tile forming one piece. They were rather bulky, weighing around 30 kg (66 lb) a piece. Being more expensive and labour-intensive to produce than thatch, their introduction has been explained by their greatly enhanced fire resistance, which gave desired protection to the costly temples (Örjan, 1990).

The spread of the roof tile technique has to be viewed in connection with the simultaneous rise of monumental architecture in ancient Greece. Only the newly appearing stone walls, which were replacing the earlier mud brick and wood walls, were strong enough to support the weight of a tiled roof. As a side-effect, it has been assumed that the new stone and tile construction also ushered in the end of 'Chinese roof' (*Knickdach*) construction in Greek architecture, as they made the need for an extended roof as rain protection for the mud brick walls that were obsolete (Goldberg, 1983).

The production of dutch roof tiles started in the 14th century AD, when city rulers required the use of fireproof materials. At the time, most houses were made of wood and had thatch roofing, which would often cause fires to quickly spread. To satisfy demand, many small roof tile makers began to produce roof tiles by hand. Many of these small factories were built near rivers where there was a ready source of clay and cheap transport.

Materials used for roofing in buildings have evolved over time. A number of them have been deployed for specific reasons such as building, weather condition, availability, cost, durability, weight, among others. Some common ones in use are metal, asphalt, wood, ceramic, and polymers. Ceramic roof tiles are resistant to corrosion; which is common in iron

based roofing sheet, as well as high durable (Olugbenga, A., Kolapo, O., Oludare, O., and Abiodun, O., 2007).

2.5 Grog

Grog, generated after the firing stage of ceramics, can eventually be used as non-plastic material added to the body in the proper ceramic processing. The main advantage of the grog addition is to facilitate easy and flawless drying stage. The morphology and size of the grog particles promote an increase in the permeability of the green body that makes easier the elimination of the extrusion water thereby facilitating the drying process (Beltrán, 1995). The grog may also optimize the workability of high plastic bodies and cause desired aesthetic effects in the surface of the products. However, the grog is generally detrimental to the mechanical strength of the pieces (RipoliFilho, 1997). Nevertheless, if the grog is fired a second time, above its original processing temperature, reactions and transformations may still occur. As stated by Vieira *et al* (1997), the use of grog produced at temperatures around 600°C, and added up to 20 wt.%, into a roofing tile ceramic body fired at 970°C, did not change the porosity of the fired pieces. The water absorption and mechanical strength did not practically suffer significant modifications. In this way, the grog addition brings advantages during the drying stage, without any detrimental effect to the fired ceramic properties.

Grog is a generic term referring to granular material made by grinding brick or other fired ceramic (although it can also be made by crushing certain natural minerals or artificially by calcining clay mineral and grinding it). Grogs are added to bodies to improve drying performance, reduce drying shrinkage, improve fired abrasion resistance, reduce thermal expansion, reduce fired shrinkage, reduce density and impart visual character. Refractory grogs are available as well as ones with low thermal expansion.

Companies manufacturing grogs face technical challenges to maximize the amount of usable material since the grinding process produces a lot of particles that are too fine to be used.

Coarser grog particles are thus more difficult to manufacture. Grog additions improve drying properties simply because the clay shrinks less and because the individual grog particles terminate micro cracks before they become big cracks. The porosity of a grog's particles, their surface texture and their shapes are also important in the dynamics of how it affects clay body working and drying properties. While it may seem that adding a grog with a wide range of sizes to a clay body will produce the maximum benefit, this is not normally the case. Generally, the highest percentage of the largest particles that can be tolerated should be employed, this has the greatest reducing effect on the shrinkage. Plastic modelling and pottery throwing bodies can still feel quite smooth when they have 20-40 mesh size of grog particles as long as the body is very plastic. Often, silica sand is incorporated with a grog addition to supply another specific range of particle sizes. It is possible to achieve a pressing or non-plastic forming body with almost zero shrinkage by mixing a body with 90% or more grog. The heavy refractories industry commonly uses a 50% 4-16 mesh, 10% 20-36 mesh, 40% 40-60 mesh mix of grog and a deflocculated slip to bind them together for drying. This principle can be extended to almost any grogged clay body. Hansen, (2008)

Grog is also used to increase pore space in the matrix to enable quicker venting of water vapour during drying and gases of decomposition during firing. A sculpture clay body, according to Hansen (2008) for example, typically has 15-25% grog (but can have much more).

Since grog is typically pre fired, it does not normally undergo a firing shrinkage (unless the body in which it is a part is fired to a temperature higher than what the grog was initially fired at). This means that the more grog is added to a recipe, the less the clay shrinks during firing.

The effect can be quite dramatic. For example, some clay bodies normally have a fired shrinkage of 5.5%, but with an addition of 15% of 20-48 mesh size of grog and 15% of 70 mesh size of silica sand, the fired shrinkage drops to 2.5% while maintaining the same degree of vitrification. Fired properties of grog-containing bodies are also affected by the hardness, colour, porosity and impurity content of the grog particles.

2.6 Body

Sullayman, (1991) describes a body as a combination of two or more different clays or often other minerals, to form the structure of ceramic wares. It is created by blending different clays or by adding to clays other materials such as feldspar and flint, in order to produce a desired workability or finished result. Mixing the right raw clay materials, in the right order, affects clay body performance. A body is a result of a man's technology. Clay is a natural product, though possibly simply processed to make it homogeneous. The bodies for industrial production of traditional ceramics are composed of various typologies of raw materials in amounts characteristic of the product desired.

Peterson, (2011) referred to clay body as the clay mixture that is used in forming objects. It may have only one specific type of clay in it, but it is more likely to consist of a mixture of different types of clays. Other additives may also be introduced into the mixture. Each specific ingredient added gives the clay particular attributes. Clay bodies undergo several changes during drying and firing stages as a result of physical, chemical and mineralogical modifications (Aramide 2012). The knowledge of these characteristics can help for a better exploitation and eventually may open-up new areas of application.

Clay body refers to specific composition of clay types, and preparation to meet required needs for the production and uses of ceramic objects. Kalilu, R. O., Akintonde, M.,

and Ayodele, O., (2006) observe that the two major types of clay are the foundation of three basic types of clay bodies; earthenware, stoneware and porcelain, whose maturing temperatures range between 750^{o}C and 1150^{o}C, 1150^{o}C and 1350^{o}C as well as 1400^{o}C and 1700^{o}C respectively. These clay types form the rudiments for other clay bodies. However, clay body formations which are varying from place to place have been documented by Singer and Singer (1963), Cardew (1967), Rothenberg (1972), Daly (1995), Rhodes (1998), Fournier (2000), among others.

In South-western Nigeria, composition of clay bodies is not also alien to traditional potters as they usually combine two or more clay types to form clay bodies in their various pottery centers according to their understanding of different types of clays that exist in their localities in order to give more strength, as well as colour to their pottery wares during firing (Abiodun and Akinde, 2013).

In recent time, there are a lot of clay body compositions that were developed in various pottery/ceramic workshops and industries, as well as art schools. For instance, certain clay body specification may be for strength or aesthetic, especially to achieve physical colour effect such as mattness, transparency and translucency. Clay body type may also be selected to appropriately accept a particular glaze batch on a corresponding body to withstand common glaze flaws such as; crazing, dunting, pine-holing, crawling and running. Physical strength of clay during throwing or making of a big hand built ceramic objects, as well as shrinkage degree considerations are also required. Sometimes, ceramic objects required for chemical use must also be composed of non-corrosive or non-absorbent terracotta and glaze bodies. This type of body is also highly essential for ceramic objects in use for mechanical devices or processes. Other considerations for clay bodies for ceramic objects used in optics requirement are light reflective, light transmitting in colour wave length as well as

transparency and translucency within ceramic material (Daly, 1995, Rhodes, 1998, and Fournier, 2000).

2.7 Clay

Clay is an impure hydrated aluminum silicate that results from the weathering of igneous rocks in which feldspar is the original material.

They may be expressed as follows:

$$K_2O.\ Al_2O_3.\ 6SiO_2 + FCO_2 + 2H_2O \longrightarrow K_2CO_3 + Al_2O_3.\ 2SiO_3.2H_2O + 4SiO_2$$

Potash feldspar Kaolinite Silica

Clay is the name generally given to compacted sedimentary rocks deriving from alterations of primary rocks. Clay is the end product of weathered feldspar that the earth used to contain through chemical action in the form of acid bearing rain (weathering). The clay formed by this action and remain at the place of formation is known as primary clay. It is popularly called kaolin or china clay. Secondary clays are the ones that have travelled or have been transported from the formation site by water or other agents of erosion. They are stoneware clay, fire clay, ball clay, etc.

Clay based minerals are the main constituents of ceramic bodies. Their amounts generally range from 40 to 60 wt %. They confer plasticity and workability in the green state and furnish the main oxides involved, with fluxes and sintering aids, in the consolidation mechanism of the body during firing.

2.8 Ball Clay

Ball clay is a highly plastic clay, usually light in colour, which is the basis of many potting bodies. Alone, it tends to be too fine and slippery for use, but additions of sand, grog,

coarser and less-plastic clays actually improves its workability. Ball clays are often included in glazes to assist suspension of the slop and provide adhesion before firing. They introduce aluminium oxide and silica as does as china clay but they are not so white. Pure clay is aluminium oxide and silica, silica provide glass and aluminium oxides provide stiffening.

2.9 Industrial Waste

The ceramic industry is capable of incorporating and reusing different types of industrial waste materials (Husam 2010). World development is based on the ability of industries to serve the human daily needs. The development comes with a high price of waste materials. The recycling phenomenon and the application of waste material as raw material for relevant industries or even as a replacement or enhancement of production flow in relevant industries have caught the attention of many countries all over the world. The waste materials can be utilized as raw materials for manufacturing or even as a means to improving the ultimate product quality.

Other researches have been conducted on different ceramic bodies either industrial or studio and the results have had a desirable effect on the ceramic production flow (Salehi, S., Zainuddin, N., Anwar, R., and Hassan, O., 2012) The ceramic industry is capable of putting to use enormous waste material suitable for industrial application. The reuse of waste materials as a portion of ceramic body composition can have a significant effect on the new body's physical and mechanical characteristics. Nevertheless, it is undeniable that the waste material which is being used in ceramic production must be compatible with ceramic body in the aspect of its melting point and other characteristics.

Salehi, *et al* (2012) further explained industrial wastes as raw material or part of raw material in some production process or different production could be utilized to eliminate some deficiencies.

According to Husam, (2010) clay materials used in the ceramic industry show an extensive range of compositions, which allow the incorporation of a wide variety of industrial waste materials. Some waste are very analogous in composition to the raw materials used, moreover they often contain materials that can also be helpful at improving the fabrication of ceramic products.

2.10 Types of Roofing

Throughout history and especially the past century, the styles of roofs vary from area to area. The varying designs, styles, and shapes of roofs exist and have been created to accommodate the needs of the structure they are covering. Some of the most primary needs that a structure demands from a roof are protection from the weather, overall design compatibility with the existing structure, and housing of internal elements such as piping, electrical wiring, ventilation and insulation

Roofpedia, (2015), documented the following as contemporary roofing styles available in the industry:

2.10.1 Flat Roof:

Flat roofs are common especially with commercial buildings. Flat roofs are the most simple roofs to build because they have little to no pitch. The most common types of roofing systems used with flat roofs are rubber roofing systems.

2.10.2 Hip Roof:

Hip roofs are a common residential style of roof. This type of roof is more difficult to construct when compared to flat roofs and gable roofs because they have a more complicated truss and rafter structure. A hip roof style of roof has four sloping sides with zero vertical roof lines/walls. Hip roofs can be both square and rectangular.

2.10.3 Gambrel Roof:

The gambrel style of roof is most commonly used on barns. However, it is also used in residential construction. This type of roof has the benefit of providing a good amount of space in the attic. In fact, it provides so much extra space that it is often turned into bedrooms or other living areas.

2.10.4 Dutch Hip Roof:

The dutch hip roof is basically a hip roof with a small gable at either end. The gables can be used for ventilation.

2.10.5 Shed Roof:

A shed roof is basically a flat roof but has more pitch. It is frequently used for additions on homes or other roof styles.

2.10.6 Mansard Roof:

The mansard roof is a french design and is more difficult to construct than the hip or gable roof.

2.10.7 Butterfly Roof:

The butterfly roof is a roof style that is not widely used. The style provides plenty of light and ventilation but is not effective when it comes to water drainage.

2.10.8 Winged Gable Roof:

The winged gable roof varies slightly from the traditional gable roof. It varies by extending outwards from the peak of the roof.

2.10.9 A-Frame Roof:

This type of roof is very popular for churches, cottages, homes, and other structures. The roof acts as both the roof and the walls for a structure.

2.10.10 Folded Plate Roof:

The folded plate roof has limited use in single family homes. It looks like a series of small gable roofs placed side by side of each other

2.11 Methods of Clay Roofing Tiles Production

Clay tile production begins by crushing and mixing various raw materials. The raw clays are thoroughly mixed with water and allowed to age for 4-5 days. The aging process allows the dry material to fully absorb moisture thereby improving plasticity. This increases yields from the extrusion process, and thus lowers the unit production cost.

Several extrusion machines and dies are employed to produce clay tiles of various shapes. Prior to extrusion, the clay flows through a vacuum chamber to remove air, preventing cracking of tiles during the firing process. This process is also very important for proper vitrification (conversion to a glassy state), which makes the tile weather resistant (i.e., resistant to freezing/thawing and salt intrusion. An automated cutter at the end of each extruder cuts the tile to the desired size, and trims the edges.

The wet extruded tile is then dried in a sequence of temperature-controlled chambers for about 24 hours. By reducing the excessive moisture in the tiles, this drying process reduces the probability of cracks when the tile is fired. The drying process typically starts with circulating ambient air at a temperature of about 20-30°C, gradually increasing the temperature to about 90 °C using waste heat from the kiln-cooling process. Drying reduces the tile's mass moisture content from 15% to less than 1%.

The dry raw tiles are inspected for defects before they are sprayed with glossy or matte glazes. The glaze is a mixture of water, pigments and clay additives. For the glossy finish, frits (glassy silicates), clay and colourants are added to the glazing mixture. The glazed tiles are positioned in vertical stacks or in a “standing up” position, with typically 1.25 cm (1/2”) spacers to allow an even heat distribution in the kiln. Even heating yields evenly coloured tiles with good mechanical properties.

The glazed tiles are then passed through a kiln fired for 14-20 hours, depending on the production schedule. The kiln has three stages preheat, heating and cooling. In the preheating zone, the tiles are gradually heated to about 700 °C by warm drawn air from the heating zone. In the heating zone, the tiles are directly fired, reaching a maximum temperature of about 1050 °C. Then the tiles are gradually cooled to about 300- 400 °C by drawing outside air through the kiln. The clay tile is ready for shipment as soon as it is removed from the kiln and cools to an ambient temperature. The clay tile colours are permanent and do not fade with exposure to the sun (Akbari, H., Levinson, R., and Berdahl, P., 2003).

2.12 Wet Litter in Poultry Management

To obtain maximum production and profitability from poultry, good management of the poultry house is essential. Litter in poultry is a combination of bedding materials including excreta and waste water and litter condition significantly influences the poultry environment and poultry performance eventually. Among other factors which contribute to poor and deteriorated nature of poultry litter are management factors. These management factors include Climatic conditions such as wet and humid weather and very cold temperatures that causes wet litter problems which is inimical to proper poultry farming conditions (Bharti, 2008).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter describes the methodology used in the development of grogged ceramic roofing tiles. This involved field trips to clay deposits in Zaria and environs, production of grog in the Department of Industrial Design, Ahmadu Bello University, Zaria, the design processes, sourcing of raw materials, physical and mechanical testing of materials. It also contains the processes involved in producing the roofing tiles.

Sullayman in Mohammed (2014) defines research design as "the arrangement of conditions for the collection and analyses of data in a manner that aims at providing both external and internal validity to the findings of the investigation." In another dispensation,

Adetoro in Anyaoha (2010) states that "the thoroughness of investigators, sample collection, analysis and adequacy of reporting the findings and validity of procedure adopted, adds quality to the research."

3.2 Population

The population of this study comprised of ball clay which was sourced from three locations. Bomo in Zaria, Rafin Tukurwa also in Zaria and Zawan in Jos South Local Government Area of Plateau State. These materials were chosen prior to their known physical, chemical and thermodynamic properties as obtained from available literature and from professionals within the field.

3.3 Sampling

The three clay samples were processed separately, with plasticity tests carried out to determine their suitability. Rectangular slabs were made out of them to ascertain their dry shrinkage and fired shrinkage properties also. These physical and Thermodynamic tests revealed results that suggest the suitability of these samples for the purpose of this research. However, Bomo secondary clay was selected due to its superior qualities, popularity for research in Zaria and its availability and abundance in the research area.



Plate I : Site where the Raw Materials were sourced.

Source: Research Photograph, Emennaa (2015)



Plate II: Site of the Raw Materials in Bomo, Zaria, Kaduna State, Nigeria

Source: Research Photograph, Emennaa (2015)



Plate III: Collection of Bomo clay from the Site in Zaria, Kaduna State

Source: Research Photograph, Emennaa (2015)

3.4 Beneficiation of Raw Materials

The raw materials were transported to the Department of Industrial Design, (Ceramic section) Ahmadu Bello University, Zaria, where they were processed.

3.4.1 Ball Clay

The clay was processed by manually crushing it into smaller particles after which it was soaked in water in a container for several days until it disintegrates into an almost even slurry in readiness for sieving. After sieving to remove impurities, the clay particles were left to settle, and decanting was carried out to achieve the slurry. The slurry was then poured into Plaster bats meant for absorbing water from it and when the clay had reached the right plastic consistency, it was removed from the bats and stored.

3.4.2 Grog beneficiation

Dried lumps of treated clay were fired up to a temperature of 1000°C. To obtain grog, the fired clay was hand crushed with a hammer to reduce its lump sizes. The jaw crusher in the Department of Industrial Design, Ahmadu Bello University, Zaria was used to further crush down the lumps into finer particles before being screened through 20 mesh size. This corresponds to approximately 840 microns as reported by Vieira, (2004).

3.5 Characterisation of Materials

Testing the mineralogical composition of different materials used in ceramic production is important because these materials have great influence on the behaviour and final properties of the fired product, King in Opoku (2015). In this regard, the ball clay used as samples for this study were analyzed using x-ray fluorescence spectrophotometer (XRF). The test was carried out at the Nigerian Geological Survey Agency, National Geosciences Research Laboratory (NGRL), Kaduna, Nigeria.

3.6 Roofing Tiles Structure and Design

Models were explored and various roofing tiles designs considered for the production of the tiles. Two clay roofing tile designs were considered for this research. They include The Spanish Individual S- tile and C Interlocking tile. These were chosen due to their preference in the industry and their peculiar qualities. The Spanish high profile roofing tiles was eventually adopted principally due to its high profile structure. The high profile nature of the Spanish tile is an advantage because it allows water let down/ run off easily as suggested by Institute of Human Settlement (1994) and Inspectapedia, (2015).

3.7 Mould Making

Following specifications of two roofing tiles considered for the research as suggested by CarsonDunlop, (2010) in Inspectapedia, (2015), moulds were fabricated using mild steel sheets of 2.5mm and 3mm. Arc welding machine and electrodes of gauge twelve (12) were used. This was first done by outlining the various shapes of the proposed moulds on the metal sheet and using a Jigsaw machine to cut them out. A Welding machine was then employed to weld the different pieces together to form both negative and positive molds of both tiles. Care was taken to ensure that the metal sheets were welded without any signs of giving way due to production pressure as suggested by Sullayman, (2006). See plates IV to VII



Plate IV: Materials Involved in Mold Fabrication including Jigsaw, Try Square, Plier and Measurment Tape.

Source: Research Photograph, Emennaa (2015)



Plate V: Alignment of Metal Components for Proper Welding

Source: Research Photograph, Emennaa (2015)



Plate VI: Welding of the Different Metal Components together to Achieve Moulds

Source: Research Photograph, Emennaa (2015)



Plate VII: Welding and Reinforcement to Achieve Strong and Durable Metallic Moulds

Source: Research Photograph, Emennaa (2015)

3.8 Body Formulation

Jaw crushed grog materials that have been screened through 20 mesh size size which is approximately 840 microns as suggested by Vieira, (2004), were made in additions of 5, 10, 15, 20 and 25 wt.% to the plastic clay body. See table 1 for the composition of materials in the blend. Samples were mixed and kneaded for proper homogeneity. It was allowed to age for a period of seven days to help in the production, drying and handling of the products (Opoku, 2015).

Table 1: Blends of grog and ball clay in percentages

Body Composition	Clay Body T1 (5%grog)	Clay Body T2 (10%grog)	Clay Body T3 (15%grog)	Clay Body T4 (20%grog)	Clay Body T5 (25%grog)
Ball Clay	950g	900g	850g	800	750g
Grog	50g	100g	150	200g	250g
TOTAL	1Kg	1Kg	1Kg	1Kg	1Kg

Source: Studio Research, Emennaa (2015)

3.9 Production of Test Specimen

The test specimens were produced according to test requirements. Example, the test slabs for the determination of Tensile strength of the tiles were required to be in a dumbell shape (approximately 10mm grip area and 15mm x 6mm gage section in between) for it to effectively fit into the tensometer before load application while test samples for the determination of the Cold Crushing strengths were produced and cut into a rectangular bar of Area 5.5cm ^{3}**.**



Plate VIII: Production of the Dumbell Shape of Material for Tensile Testing

Source: Research Photograph, Emennaa (2015)

3.9.1 Drying and Sintering of Test Tiles

The tiles were placed on a rack to dry at room temperature. This process allowed air to circulate on all sides of the tiles and as such they dried evenly without warping.

The electric kiln at the foundries department of the National Metallurgical Development Centre, Jos, was used for the sintering of the tiles to the varying temperatures of 900^0C, 1000^0C and 1150^0C. The kiln at the NMDC was particularly effective as it had a digital temperature monitoring and display system. This was quite helpful in the area of proper sample monitoring to required temperatures. (See plate IX).



Plate IX: Sintering of Sample Tiles using Electric Kiln at the Foundries Section of N.M.D.C, Jos

Source: Research Photograph, Emennaa (2015)



Plate X: Dumbell Shaped Test Samples Sintered to 1150^{O}C, 1000^{O}C and 900^{O}C

Source: Research Photograph, Emennaa (2015)

3.10 Property Tests

3.10.1 Dry Shrinkage Analysis

The shrinkage test was conducted by first preparing and rolling into rectangular shaped slabs. A 10cm line was drawn across the various samples before drying on a bat in order to allow for proper and gradual drying. The lines were measured again after drying to ascertain the present length which was employed to determine its percentage shrinkage using the following formula as adopted by Rhodes (1957) in Achilam (2010):

$$\%\text{linear shrinkage} = \frac{\text{plastic length} - \text{dry length}}{\text{plastic length}} \times 100$$

3.10.2 Fire Shrinkage Analysis

The tiles used in the initial test are fired to 1000°C to remove molecular water and achieve hardness. The previous 10cm lines are measured again to get their current values after firing. As suggested by Rhodes (1957) methods in Achilam (2010), the following formula was employed to calculate the percentage fire shrinkage of the tile.

$$\%\text{fire shrinkage} = \frac{\text{dry length} - \text{fired length}}{\text{dry length}} \times 100$$

3.10.3 Tensile Strength Analysis of the Tile

Tensile properties often are measured during development of new materials and processes, so that different materials and processes can be compared. They are also used to predict the behaviour of a material under forms of loading. ASM International, (2004). This test was carried out at the Strength of Materials Laboratory of the Department of Mechanical Engineering, Ahmadu Bello University, Zaria. A Hounsfield Tensometer was used to test all the tiles sintered at the various temperatures of $900^{O}C$, $1000^{O}C$ and $1150^{O}C$. Three tiles each of every single composition and temperature range were tested and the average result taken.

The following formula was employed to calculate the tensile strength values of the tiles:

Tensile Strength (N/mm) = Force (kN)

Area (mm^2)



Plate XI: Load Application on the Test Pieces Using the Tensometer at the Strength of Materials Laboratory, Department of Mechanical Engineering, A.B.U, Zaria.

Source: Research Photograph, Emennaa (2015)

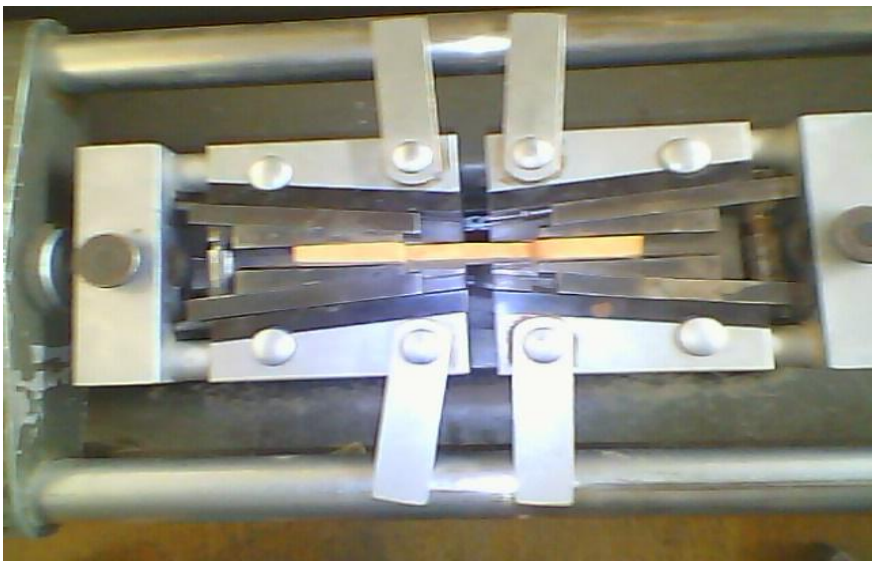


Plate XII: Tensometer Showing the Grip of a Dumbell Shaped Test Piece Prior to Load Application.

Source: Research Photograph, Emennaa (2015)

3.10.4 Cold Crushing Strength (CCS) Analysis

Cold crushing strength (CCS) is the product' s ability to resist failure under a compressive load, at room testing machine until the sample fractures (or fails) ASTM, (1985). This property test was carried out at the Foundry Department of the National Metallurgical Development Centre, Jos. All the tiles were tested using the Form + Test Seidner Machine (See Plate XIII). Prior to the crush testing, the tiles were taken to the fabrication department where they were cut down to a uniform area size (5.5cm^2).

The cold crushing strength was calculated using the following formula

$$\text{CCS (kg/cm}^2\text{)} = \frac{\text{Mass (kg)}}{\text{Area (cm}^2\text{)}}$$



Plate XIII: Form + Test Seidner Machine used for Cold Crushing Test Analysis at N.M.D.C, Jos.

Source: Research Photograph, Emennaa (2015)

3.11 Tile Production

The lever pressing technique which comprises of the following processes were employed: kneading and wedging of the clay to free air pockets, slabing on a flat surface for eveness, greasing of the mould to enhance easy removal, loading of clay onto the mould, pressing, lifting, demoulding, drying and firing. This processing sequence was adopted by Achilam, (2010). A hydraulic press machine was employed to press the tiles at a pressure of about 15.45MPa as suggested by Sullayman (2006) and also, Opoku (2015). See plates XIV – XIX.



Plate XIV: Application of grease to the mould to facilitate demoulding.

Source: Research Photograph, Emennaa (2015)



Plate XV: Loading of Clay Slab onto the Mold Prior to Pressing

Source: Research Photograph, Emennaa (2015)



Plate XVI: Hydraulic Machine Loaded Ready for Pressing

Source: Research Photograph, Emennaa (2015)



Plate XVII: Application of Pressure to Press the Tiles

Source: Research Photograph, Emennaa (2015)

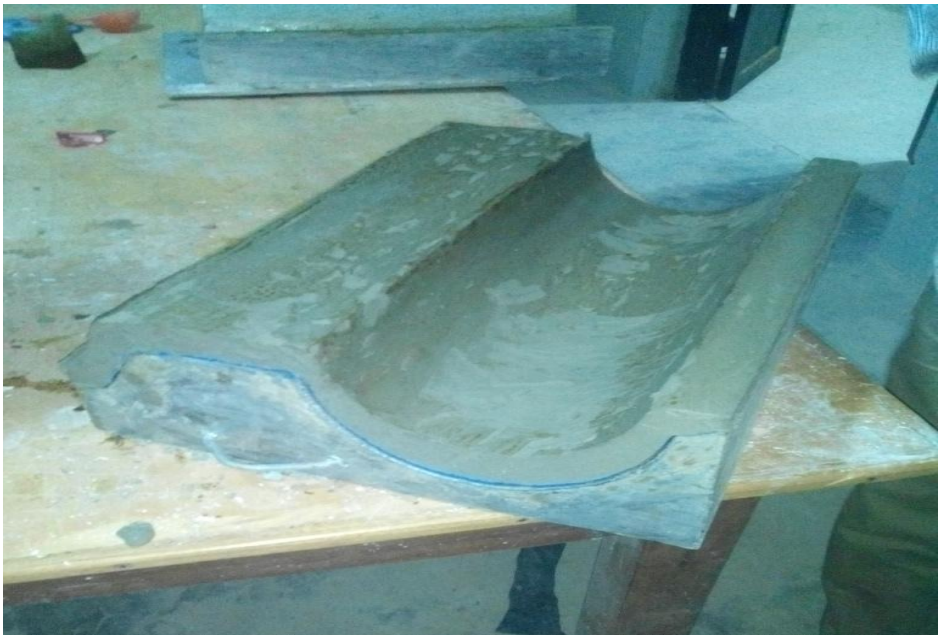


Plate XVIII: Demoulding of a Pressed Tile

Source: Research Photograph, Emennaa (2015)



Plate XIX: Pressed Roofing Tiles Ready for Drying

Source: Research Photograph, Emennaa (2015)

3.12 Drying of tiles

Carlos (2008) suggested the use of appropriate conditions of placement, temperature, humidity and time during the drying of tiles since inappropriate drying may cause a tile to cut or break. Thus, the tiles were places on a rigid rack after production to ensure even and proper drying .

3.13 Firing of Roofing Tiles

At the end of the drying process, the tiles were fired gradually to 1150°C. The firing was carried out in a digital electric kiln under oxidized atmosphere at the Department of Chemical Engineering, Faculty of Engineering, Ahmadu Bello University, Zaria.

CHAPTER FOUR

RESULTS

4.0 Introduction

Results of the various physical property and mechanical tests are presented, analysed and discussed towards reaching a beneficial product. The property tests include linear and firing shrinkage, water absorption, tensile strength and cold crushing strength.

4.1 Results of Plasticity Test

Plasticity tests carried out on the clay sample obtained for the research proved to be plastic. When bent or coiled to a meeting point, it did not reveal any form of breakage or cracks.

4.2 Results of Characterisation of Materials

Table two (2) presents the chemical composition of the raw material (Bomo clay) used for the study by means of x-ray fluorescence spectrophotometer (XRF)

Table 2 XRF Analysis of Bomo Clay sample

ELEMENT	CONCENTRATION
Na_2O	0.090wt%
MgO	0.866 wt%
Al_2O_3	19.569 wt%
SiO_2	67.336 wt%
P_2O_5	0.000 wt%
SO_3	0.411 wt%
CI	0.017 wt%
K_2O	2.241 wt%
CaO	1.186 wt%
TiO_2	1.750 wt%
Cr_2O_3	0.011 wt%
Mn_2O_3	0.060 wt%
Fe_2O_3	6.408 wt%
ZnO	0.025 wt%
SrO	0.028 wt%

Source: Nigerian Geological Survey Agency, National Geosciences Research Laboratory (NGRL), Kaduna, Nigeria. (2015)

This test revealed a large presence of silica and alumina in the sample which accounted for 67.336 and 19.569 Wt% respectively. There is about 6.408 Wt% of iron oxide in the clay while other elements like potassium oxide, calcium oxide and titanium dioxide accounted for

2.241 Wt%, 1.186 Wt% and 1.750 Wt% respectively. Other trace elements complete the composition of the clay sample as seen in the table above (Opoku 2015).

4.3 Colour results of the Bomo clay sample

Colour variations were noticed in the different fired samples as the tiles had a darker red hue as the temperature increased. Also, the sound of hitting the tiles fired to 1150^{o}C together, showed they had properly sintered compared to the other tiles fired to 900^{o}C and 1000^{o}C.

4.4 Results of Dry Shrinkage Analysis

Samples of the different compositions were measured after pressing into rectangular slabs in their wet state. The same pieces after proper drying, were also measured with records taken. The dry shrinkage results are obtained using this formula

Dry Shrinkage = Wet Length – Dry Length / Wet Length X 100

4.5 Firing Shrinkage Analysis

The same slabs used in determining the dry shrinkage percentage after measurement, are subjected to a firing of 1150^{0} Celsius. The process of firing aids greatly in closing up bodies of clay as temperature advances. They are measured once again with the Firing shrinkage calculated using the following formula

$$\frac{\text{Dry Length Fired Length X 100}}{\text{Dry Length}} = \frac{\text{Firing Shrinkage}}{1}$$

These formulae are as documented by (Achilam, 2010) and (Mohammed, 2014).

4.6 Dry Shrinkage and Firing Shrinkage results

The results of both shrinkage tests are presented in table 3. This indicates that sample T5 with 25% of grog as having the lowest fire shrinkage of 1.1% while the highest shrinkage value

was attributed to sample T1. Sample T4 with 20% grog, had the lowest dry shrinkage rate of 5% while samples T1,T2 and T3 accounted for 6.5% dry shrinkage, representing the highest as seen in table 6.

Table 3 Dry Shrinkage and Firing Shrinkage results

SAMPLE	DRY SHRINKAGE (%)	FIRED SHRINKAGE (%)
T1 (5% grog)	6.5	3.2
T2 (10% grog)	6.5	2.1
T3 (15% grog)	6.5	1.6
T4 (20% grog)	5	1.6
T5 (25% grog)	6	1.1

Source: Studio Research, Emennaa (2015)

4.7 Water Absorption Test Results

Water absorption is a key factor affecting durability of ceramic tile samples. The less water infiltrates into a ceramic tile sample, the more durable the product is and the better its resistance to the natural environment (Rajamannan, B., Kalyana Sundram, C., Viruthagiri, G., and Shanmugam, N., (2013). The test specimens which are in the form of bars, are dry weighed and submerged into water for 24 hours after which they are removed and excess water on them were cleaned off with a piece of dry cloth. The tile specimens are then weighed again to determine the rate of water absorption where,

W1 – Weight of the dry specimen and

W2 = Weight of the specimen after 24 hours immersion into water.

The following formula was employed to calculate the water absorption rate and the results presented in table 4 below.

$$\frac{\text{Saturated weight} - \text{Dry weight}}{\text{Dry Weight}} \times \frac{100}{1} = \text{Water absorption}$$

Table 4 Water Absorption Test Results

SAMPLE	900^0 CELSIUS	1000^0 CELSIUS	1150^0 CELSIUS
T1 (5%)	16%	8%	6%
T2 (10%)	16%	8%	6%
T3 (15%)	16%	8%	6%
T4 (20%)	16%	8%	6%
T5 (25%)	16%	8%	7%

Source: Studio Research, Emennaa (2015)

Results of the water absorption tests indicate that samples T1, T2, T3 and T4 fired to the temperature of 1150^oC had the lowest water absorption percentage of 6%. This result is compatible with Industry standards that recommend that clay roofing tiles water absorption percentage should be 6 percent. This was reported by Roundhay Roofing and UK Federation of Roofing Contractors, (2015).

4.8 Tensile Strength Results of the Tiles

The results of three samples of each composition fired at the three varying temperatures of 900, 1000 and 1150^0 and tested to determine the average tensile strength of the composition are presented here . The results are shown below on Table 5, 6 and 7 and discussed:

Table 5 SAMPLES FIRED TO 900^{0}C

Sample	Thickness (mm)	Width (mm)	Area (mm^2)	Force (kN)	Tensile strength (N/mm^2)	Average tensile strength of three samples (N/mm^2)
T1 (5%) 1	5.7	15	85.5	84000	982.46	
2	6	14.7	88.2	108000	1224.49	
3	6	15	90	72000	800	**1002.32**
T2 (10%) 1	5.4	13.8	74.5	84000	1127.52	
2	5.4	16	86.4	72000	833.33	
3	5.8	15	87	96000	747.20	**902.68**
T3 (15%) 1	6	14	84	72000	857.14	
2	5.2	14.8	77	48000	623.38	
3	5.8	14	81.2	60000	738.92	**739.81**
T4 (20%) 1	6	14	84	60000	714.29	
2	5.3	15	79.5	48000	603.77	
3	5.5	14.6	80.3	60000	747.20	**688.42**
T5 (25%) 1	6.2	15	93	108000	1161.29	
2	6	15	90	96000	1066.67	
3	5.7	15.2	86.6	90000	1039.26	**1089.07**

Source: Studio Research, Emennaa (2015)

Table 6 SAMPLES FIRED TO 1000^{0}C

Sample	Thickness (mm)	Width (mm)	Area (mm^2)	Force (kN)	Tensile strength (N/mm^2)	Average tensile strength of three samples (N/mm^2)
T1 (5%) 1	6.8	14.7	100	84000	840	
2	6.2	14.8	91.8	60000	653.59	
3	6	14.4	86.4	60000	694.44	**729.34**
T2 (10%) 1	6	14.4	86.4	72000	833.33	
2	5	15	75	84000	1120	
3	5.3	15	79.5	84000	1056.60	**1003.31**
T3 (15%) 1	5.2	15	78	72000	923.10	
2	5.2	15	78	108000	1384.62	
3	5.7	15	85.5	96000	1122.81	**1143.51**
T4 (20%) 1	6.2	14.5	89.9	132000	1468.30	
2	5.3	14	74.2	84000	1132.10	
3	6.2	14.7	91.1	108000	1185.51	**1261.97**
T5 (25%) 1	6	15	90	156000	1733.33	
2	5	15	75	120000	1600	
3	5.7	15	85.5	120000	1403.51	**1578.95**

Source: Studio Research, Emennaa (2015)

Table 7 SAMPLES FIRED TO 1150^{0}C

Sample	Thickness (mm)	Width (mm)	Area (mm^2)	Force (kN)	Tensile strength (N/mm^2)	Average tensile strength of three samples (N/mm^2)
T1 (5%) 1	5.8	16	92.8	348000	3750	
2	5.4	16	86.4	408000	4722.22	
3	5.4	13.8	74.5	204000	2738.25	**3736.82**
T2 (10%) 1	5.7	14	79.8	192000	2406.02	
2	5.2	14.8	77	132000	1714.29	
3	5	14.7	73.5	240000	3265.31	**2461.87**
T3 (15%) 1	5.8	15	87	120000	1379.31	
2	5.2	15	78	240000	3076.92	
3	5.8	13.5	78.3	180000	2298.85	**2251.69**
T4 (20%) 1	5.3	13	68.9	156000	2264.15	
2	5.8	14.8	85.8	132000	1538.46	
3	5.7	14.8	84.4	180000	2132.70	**1978.44**
T5 (25%) 1	5	14	70	120000	1714.29	
2	6	14.3	85.8	132000	1538.46	
3	5.2	15	78	144000	1846.15	**1699.63**

Source: Studio Research, Emennaa (2015)

These results as obtained from the Strength of Materials Laboratory of the Mechanical Engineering Department of the Ahmadu Bello University, Zaria, affirmed the behaviour of the various materials under load and showed that the samples which fired up to 1150^{o}C as the samples that performed best. The strongest sample was sample T1, which registered 3736.82 N/mm^2 as its tensile strength. This sample contained 5% grog addition to the clay body as seen in table 3. It was also observed that tensile strength increased with a reduction in grog application. These results appear to agree with RipoliFilho, (1997) who asserts that grog is generally detrimental to the mechanical strength of clay bodies but rather optimizes the workability of highly plastic bodies.

4.9 Cold Crushing Strength Results of the Tiles

The results of Cold Crushing Strength of the various bodies are presented and discussed below:

Table 8 COLD CRUSHING STRENGTH RESULTS OF BATCH A (900^0 CELSIUS)

Sample	Length (cm)	Breadth (cm)	Area (cm^2)	Force (kN)	Mass (kg)	c.c.s (kg/cm^2)
T1 (5%)	2.5	2.2	5.5	12.5	1250	227.27
T2 (10%)	2.5	2.2	5.5	12.6	1260	229.09
T3 (15%)	2.5	2.2	5.5	12.53	1253	227.81
T4 (20%)	2.5	2.2	5.5	12.7	1270	230.90
T5 (25%)	2.5	2.2	5.5	12.4	1240	225.45

Source: Studio Research, Emennaa (2015)

Table 9 BATCH B (1000^0 CELSIUS)

Sample	Length (cm)	Breadth (cm)	Area (cm^2)	Force (kN)	Mass (kg)	c.c.s (kg/cm^2)
T1 (5%)	2.5	2.2	5.5	13.7	1370	243.63
T2 (10%)	2.5	2.2	5.5	13.3	1330	241.81
T3 (15%)	2.5	2.2	5.5	13.5	1350	245.45
T4 (20%)	2.5	2.2	5.5	13.6	1360	247.27
T5 (25%)	2.5	2.2	5.5	13.7	1370	249.09

Source: Studio Research, Emennaa (2015)

Table 10 BATCH C (1150^0 CELSIUS)

Sample	Length (cm)	Breadth (cm)	Area (cm^2)	Force (kN)	Mass (kg)	c.c.s (kg/cm^2)
T1 (5%)	2.5	2.2	5.5	15.7	1570	285.45
T2 (10%)	2.5	2.2	5.5	15.6	1560	283.63
T3 (15%)	2.5	2.2	5.5	15.5	1550	281.81
T4 (20%)	2.5	2.2	5.5	15.4	1540	280
T5 (25%)	2.5	2.2	5.5	15.3	1530	278.18

Source: Studio Research, Emennaa (2015)

These results of the cold crushing strength of samples as carried out, indicate that the sample with the highest cold crushing strength, are the samples containing 5% grog addition, fired up

to 1150^{o}C. This sample was able to resist failure under compressive load of 285.45 kg/cm^{2}. The sample with 25% addition of grog, fired at 900^{o}C failed under a compressive load of 225.45 kg/cm^{2} and turned out to have the lowest cold crushing strength. The result of the samples sintered to the highest temperature of 1150^{o}C revealed that as the grog addition increased, the cold crushing strength reduced.

4.10 Results of the Mould Production and Use



Plate XX: Finished (negative and positive)Tile Moulds After Fabrication

Source: Research Photograph, Emennaa (2015)

4.11 Results of the Tile Production

The fabricated metallic moulds proved to be efficient in the pressing of the roofing tiles without structural problems identified on the moulds. Tiles were produced effectively with the mould still remaining intact for further use.

Pressed and dried tiles sintered to 1150^{o}C using a digital electrical kiln, were found to have properly fired to a reddish bisque colour. They had features of ceramic clay roofing tiles obtainable in the tile market.

The tiles met the standards set by the Institute of Human Settlement (1984) whereby human weights of 94 and 100 kg were rested on the tiles without breakage. These weights applied exceeded the 55, 60 and 65 kg weights applied by Achilam (2010), proving that installation and further roof maintenance can be carried out on these ceramic roofing tiles with minimal damage and losses.



Plate XXI: Sintered Tiles, Finished and Ready for Assembly

Source: Research Photograph, Emennaa (2016)

CHAPTER FIVE

5.0 Summary, Conclusions and Recommendations

5.1 Introduction

This study investigated the use of grogged Secondary clay from Bomo, Zaria, Nigeria for the development of roofing tiles. This section embodies the summary of observations made in the different experiments carried out at various stages of the research towards the achievement of the set objectives of the study. Specific and yet far reaching recommendations are hereby proffered.

5.2 Summary

The collection of various materials and their stages of beneficiation formed the first stage of this research. It was possible to obtain the Bomo clay and also fire dried samples of it to obtain grog. Body formulations were carried out with additions of crushed and sieved grog to the plastic clay body in different percentages (5,10,15,20 and 25%). Test samples were made in line with specifications for both tensile and cold crushing strength analyses.

Equal numbers of the different compositions were subjected to sintering at three separate temperatures of 900^{o}C, 1000^{o}C and 1150^{o}C. These were tested for linear/firing shrinkage, water absorption, tensile and cold crushing strengths, which generated values as found in the body of this write up.

5.3 Findings

i. The physical properties of the Bomo clay such as plasticity, dry and fire shrinkage were desirable for the production of roofing tiles.

ii. The elemental properties of the clays by means of x-ray fluorescence spectrophotometer revealed a wide range of constituent properties which made it suitable for ceramic roof tile production.

iii. Design and production of roofing tiles using formulated grogged body was possible and quite efficient.

iv. The mechanical property tests which include cold crushing and tensile strength tests of the roofing tile revealed the suitability of the tiles for ceramic clay roofing tile production.

5.4 Conclusion

Based on the tests and experiments carried out and their results, the following conclusions are drawn.

i. Bomo clay and its grog can be used for the development and manufacturing of durable ceramic roofing tiles.

ii. Metals as thick as 3mm can be designed, cut, measured and fabricated into viable moulds for the pressing of clay roofing tiles.

iii. Tiles fired to 1150^{o}C revealed increases in both tensile and cold crushing strengths. It was also noted that these values increase with reduced grog additions to the clay body. Also, results of water absorption indicate this tile composition to be the best.

iv. A total of two (2) roofing tiles were pressed within an hour. The time also includes the time used in the slabing and loading of the moulds. With this statistic in mind, it is estimated that a total of sixteen (16) to twenty (20) roofing tiles can be produced by two workers within the 9 working hours of a day.

v. Results from this study provides information to the ceramist, the ceramic industry, research agencies and other industries involved in the same or similar research.

5.5 Recommendations

i. It is recommended that grogged clay be beneficiated and used as a ceramic production material due to its workability.

ii. Poultry farmers should explore the use of clay roofing tiles in bird housing in order to reap from the immense economic benefits inherent in this form of poultry house roofing which includes a cooler, less heated / stressful housing.

iii. The use of roofing underlay is recommended. This is a layer of polyethene sheet that is laid on the roof prior to the installation of the clay roofing tiles. This ensures principally that any form of water intrusion is trapped. It is also useful during roof tile alignment and installation.

iv. More emphasis should be paid to the development of Industrial ceramic products that are capable of triggering small and medium scale enterprises as a catalyst in driving the nation's economy.

v. The use of grog in ceramics should be subjected to further research in order to further expand its inventory in ceramics production.

vi. It is hereby recommended also, that further research studies be carried out on the use of grogged materials in ceramic research especially in view of the country's recent commendable efforts towards economic diversification away from oil.

5.6 Contribution to Knowledge

i. This project presents information on the use of grog as an additive in the production of clay roofing tiles

ii. The study brings innovation in the area of mould design and fabrication as against the more common practice of mould casting.

iii. This work provides information to the ceramist, the ceramic research agencies as well as manufacturing industries.

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