A STUDY OF UPLAND CLAY FROM ANT-HILLS AS A REFRACTORY MATERIAL

BY

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DECLARATION

I Wamaholo Elizabeth, do hereby declare that this Dissertation has never been submitted to any institution for an academic award and it is truly my own work constituting a true record of the findings.

Signed......Elizabeth.......................................

Date ......15/01/2016...

APPROVAL

This is to certify that this Dissertation by Wamaholo Elizabeth was carried out under our close supervision and has been passed by Board of Examiners and Senate for Award of the Degree of Master of Science in Physics of Kyambogo University.

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DEDICATION

This research report is dedicated to the Little Sisters of St. Francis of Assisi in appreciation of the care and support they gave me in all situations.

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ABSTRACT

This study was purposed to investigate the suitability of upland ant-hill clays for fabricating refractory bricks. The chemical composition of the anthill clay was determined using the Atomic Absorption Spectrophotometer (GBC SavantAA) and X-Ray Spectrometry. The chemical analysis revealed the presence of the elements which included; alumina, silica, iron oxide, titanium oxide, potassium, sodium, calcium, organic carbon, phosphate, zirconium, strontium, cranium, rubidium, magnesium, manganese, copper, zinc, yttrium and nitrogen.

Wet and dry pressed samples were obtained by using the hydraulic press with a die mould (Hydraulina Laboratory Manual press- PW40) and slip casted samples were formed using a metallic brick mould. All dry pressed samples were found to be structurally inadequate due to development of strata, formation of cracks after firing. The wet pressed and slip casted samples were fired at a heating rate of 2^0C/minute to a temperature of 534^0C and held at this temperature for 1hour then heated to 1150^0C at a rate of 6^0C/minute and held for 1 hour and then allowed to cool in the furnace at a rate of 5^0C/minute. All Samples fired at 1150^0C were successfully retrieved and had no cracks or any other deformities.

The Modulus of rupture was determined using the three point loading method (LLOYD INSTRUMENTS). Thin wet pressed fired samples had high MOR average values of 13826.08KPa for Nkombe, 1963.43KPa for Namagunga and 1510.23KPa for Kyambogo. The slip casted fired samples had an average MOR of 31.60Pa for Namagunga and 117.74Pa for Kyambogo. These suggested that sample forming methods have an effect on the modulus of rupture.

The average MOR of the wet pressed fired samples of upland ant-hill clay was found to match that recommended by ASTM (American Society for Testing and Materials) standards for refractory materials and the percentage of the alumina in upland ant-hill clay showed quite close compliance with ASTM standards. This therefore means that based on the findings above, upland ant-hill clay is suitable for refractory materials.

CHAPTER ONE: INTRODUCTION

1.0 Introduction

In this chapter the following are discussed; Background of the study, statement of the problem, purpose of the study, objectives of the study, scope of the study and significance of the study.

1.1 Back ground of the study

In the past Ugandans made their dishes, art crafts, pots for cooking and fetching water among others from clay. The skills were passed on from one generation to the other. This has been neglected for years making many elite potters to quit yet pottery is one of the oldest professions of ancient Ugandans. This has led to the importation of ceramic products like refractory bricks, plates, cups, roofing tiles, art pieces, dishes, flower pots to mention but a few, from other countries like China and Italy, making Uganda to lose a lot of money every year on importation of the above products. Information from the country's Geological Survey and Mines department emphasizes the occurrence of the high quality deposits of ceramic refractory raw minerals in abundance in various parts of the country, which can be used in the production of different domestic and industrial product, Olupot ,(2006).

Traditional ceramics materials like porcelain, stoneware, earthenware, steatite and cordierite ceramics differ in chemistry phase composition, porosity and in thermal, mechanical and dielectric properties, Shuller (1997). These are used to make products such as refractory bricks, chemical, electrical, technical porcelains and china wares, and such commonly used products as fire dinnerware, wall tile, pottery, vitreous plumbing fixtures and dental porcelains, Jones, (1993).

In Uganda there are a few kilns, furnaces, steel recycling plants such as found at Jinja, Lugazi to mention but a few which are built using imported refractory bricks. The growth of the steel industry has been affected by problems associated with refractory bricks. The problems besetting the steel industry observed by Hashim (1992) are numerous: these include scarcity and cost of refractory materials, high demand for furnaces and kilns and lack of promotion of the use of locally available materials.

There are studies going on about using ball clay for production of refractory material but there are no recorded studies on the exploitation of upland clay sources like ant-hills for the production of refractory materials yet ant-hill clay exist in abundance and presently serve no economic benefit but if its potentials are properly tapped, it will help reduce pressure on refractories, conserve the country foreign reserve and above all it will cut-down refractory cost thereby making it to be affordable to most industries.

According to Stone, (1985), "an ant-hill is a pile of earth, sand, pine needles or clay or a composite of these and other materials that build up at the entrances of the subterranean dwellings of ant colonies". A new ant-hill begins underground and the mound does not appear until the colony is a year or more old. It grows rapidly and constantly being expanded to, altered or repaired. Inside the mound are the royal chamber, a maze of passages and other chambers which continue below the ground linked to a network of tunnels in the soil. The tunnels may extend for up to 100m beyond the nest and are used when the workers go in search of food (Stone and Ndu, 1985). There are various types of ant-hills made by different species of ants and most ant species make their nests underground, carving tunnels and chambers in the soil. Some of these species build large mounds of soil, twigs and pine needles over their underground nests. This particular study is focused on ant-hills which are large mounds of soil.

Ant-hills from time immemorial have been put into different uses in various parts of the world;

In Volta region including Togo and Benin ant-hill clay was predominantly used for the construction of shrines. It has also been used in building walls of houses in most countries of the Sub-Sahara Africa.

Ant-hill clay mixed with grass and river sand has been used for making fuel saving brick stoves in Mozambique and Zambia. Also it has been used as a waterproof liner for ponds and dams and an alternative to soap in India, for personal hygiene and also as a shaving cream. Traditional healers in India have used sieved ant-hill clay as a mudpack to reduce swelling and pain from injuries, as well as a cleanser (Eggleton, 2007). Ant bed clay has been used for constructing traps for coyotes in Kentucky, USA. It has also been used to reduce losses in stored yams in Nigeria. The geochemistry of ant-hill clay has been used for gold exploration in Africa and or diamond exploration in the Kimberley (Eggleton, 2007).

Australian indigenous people have traditionally used limonite oxide, obtained from termites' mounds, as an ochre pigment for painting. Termite mound clay has also been traditionally ingested as a medicinal aid in cases of diarrhea, as well as being used to control bleeding infection. The practice of eating termite mounds has even been observed among mountain gorillas in Rwanda who were found to suffer from gastrointestinal infections.

In most regions in Uganda expectant mothers eat ant-hill clay as source of iron in the body.

None of these activities involves use of ant-hill clay in the fabrication of refractory bricks. There is an opportunity which could be exploited. For instance, in Nkombe village in Mayuge district, Namagunga village in Mukono district, Kyambogo University in Kampala district and in other regions of the country there are large colonies of ant-hills which are often looked at as wastage of pieces of land. These anthills are not made use of. The idea of utilising clay from upland ant-hills as a refractory material is attractive since they are available throughout the country.

In this study, a number of experiments will be conducted in order to determine the feasibility of using upland clay resource as a raw material for the production of refractory materials.

1.2 Statement of the problem

At the moment, there is a significant increase in the construction of infrastructures like kilns and furnaces by local artisans in cottage industries and large commercial enterprises like Uganda Clays at Kajjansi and Kamonkoli near Mbale. This has led to an increase in the demand for refractory bricks required for building furnaces and kilns yet there is none that is locally produced. In order to meet the local demands, all refractory bricks have to be imported from countries like China and Italy.

The currently popular item of study is ball clay from the swamps and no effort has been recorded on studies related to the use of upland clay from ant-hills in the production of refractory material.

Most of the country side is populated by many ant-hills of unique and different shapes forming part of a beautiful landscape. These ant-hills are built through the wisdom of worker ants digging subterranean tunnels.

Although the above claims have been made, no clear and close study has been carried out on ant-hills in Uganda. It is against this background that the study on determining the possibility of using upland ant-hill clay as refractory material was carried out.

1.3 Purpose of the study

The aim of the study was to investigate the suitability of upland ant-hill clays for making refractory materials.

1.4 Objectives of the study

1. To analyse the chemical composition of upland ant-hills clays
2. To determine Modulus of Rupture (MOR) of the fabricated brick samples from upland ant-hill clay.
3. To establish whether upland ant-hill clay can be used as a refractory material: Based on three parameters namely; chemical composition, MOR and firing Temperature.

1.5 Significance of the study

The study will provide valuable information on the possibilities of exploitation of upland clay from ant-hills for the production of refractory products.

The study will also help to reduce on the heavy harvesting of ball clay so as not to exhaust known reserves for ball clay.

In addition, the study will help in establishing alternative raw materials for refractory.

Not only that but also the study will trigger innovation in other technological sectors like manufacturing of insulated tiles and electronics.

It is hoped that the study will open up further research in upland clay for the production of other ceramic materials like tea cups, plates, dishes etc.

The study will inspire scientists to think of how to help in the development of refractory products from the country' natural resources which is very important as far as industrialization of a nation and saving foreign exchange is concerned which in return will help in boosting the economy of the country by reducing the importation of refractory materials.

1.6 Scope of the study

The study was limited to;

1. The use of upland ant-hill clay from three geographical sites namely; Nkombe in Mayuge district, Namagunga in Mukono district and Kyambogo in Kampala district in Uganda.
2. The area of sampling was limited to a radius of 500m from the selected Global Positioning System (GPS) coordinates.
3. Three forming methods, which were dry pressing, slip casting and wet pressing as methods of forming the samples.

CHAPTER TWO: THEORY AND LITERATURE REVIEW

2.0 Introduction

This chapter deals with theory and related literature that are in line with the three objectives of the study namely:

1. Analysing the chemical composition of upland ant-hills clays.
2. To determine Modulus of Rupture (MOR) of the fabricated brick samples from upland ant-hill clay
3. To establish whether upland ant-hill clay can be used as a refractory material: Based on three parameters namely; chemical composition, MOR and firing Temperature.

2.1 Anthill Clay

Ant-hill clay is obtained from termite mound, while mound is a pile of earth made by termite resembling a small hill commonly known as ant-hills. Ant-hills are built of soil and earth particles which are cemented together to form hard bricklike material which are very resistant to weathering and very difficult to chip with a sharp pick. It is made of clay whose plasticity has further been improved by the secretion from the termite while being used in building the mound (Mijinyewa et al., 2007). It is therefore a better material than the ball clay in terms of utilization for moulding lateritic bricks (Odumodu, 1999, Mijinyewa et al., 2007) and this type of clay has been reported to perform better than ball clay in dam construction (Yohanna et al., 2003). The clay from the termite mound is capable of maintaining a permanent shape after moulding because of its plasticity; it is also less prone to crack when compared with ball clay. In addition, it has low thermal conductivity and expectedly reduced solar heat flow and temperature fluctuation within an enclosure (Mijinyewa et al., 2007).

Ant-hills vary greatly in shape and in sizes. Whiles some may have only one chamber of about the size of a thumb with few ants in them, some tropical ants build huge underground nests that may extend about 12m below the surface of the ground, with about ten million ants in it (Hesse, 2007). The termites' road system can be enormous and reach a radius of 50 to 100m around the nest. A series of chambers and galleries keep the interior of the mound at a constant temperature of 31^0C. This is so because strategically placed ventilation holes at the bottom of the mound allow fresh air to enter, while hot stale air is forced out through the top. Cooler air then enters the mound from an underground chamber and then circulates through the passages and cells. The termites open and close the holes to adjust the temperature as needed. A constant temperature is therefore maintained to enable them to form the fungus that is their primary food. In Zimbabwe for instance the outside temperature can fluctuate from about 2^0C at night to over 38^0C during the day. Yet the temperature inside the mound remains constant at 31^0C (Awake June 2008).

Termite mounds have been called marvels of engineering because of their wonderful nature. Their 45cm walls baked by the sun are as hard as concrete, the clay and sand cemented with saliva makes it waterproof (Awake, 2008). Ecologists view ant-hills as natural disruptions that maintain heterogeneity in an ecosystem (Wagner, 1997). Considering that the longevity of ant mound may range from 30 – 60 years, their effects on the surrounding soil and vegetation may be substantial and sustained (Kelly, 1976). These factors make ant nests important factors of many ecosystems, including the closed savanna.

2.2 Clay as a refractory

Clays are one of the oldest refractories known and are still much used and because they become plastic when mixed with water, shaping is much easier than with other refractory material. A refractory material is one which has the ability to withstand high temperature without breaking or deforming, Ryan, (1978). Refractory products are used wherever high temperatures are encountered, and include refractory bricks for furnace linings, tubes for electric furnaces, crucibles, thermocouple sheaths, refractory cements among others. According to Routschka (2004), refractories are normally used to serve the following purposes:

1. Lining of plants for thermal processes (melting, firing, and heat treatment furnaces and transport vessels).
2. Heat insulation
3. Heat recovery (regenerators and recuperators)
4. Construction of design components (functional products)

One of the physical properties which give an indication of the product's performance under specific operating conditions is Modulus of Rupture. Modulus of Rupture (MOR) indicates the product's bending or tensile strength.

Clay is a naturally occurring material composed primarily of fine-grained minerals, which show plasticity through a variable range of water content, and which can be hardened when dried and/or fired. Clay deposits are mostly composed of variable amounts of water trapped in the mineral structure by polar attraction and phyllosilicate minerals, which impart plasticity and harden when fired and/or dried. Organic materials, which do not impart plasticity are most often also found in clay deposits, Adjei (2009).

Clay minerals are typically formed over long periods of time by the gradual chemical weathering of rocks (usually silicate-bearing) by low concentrations of carbonic acid and other diluted solvents. These solvents (usually acidic) migrate through the weathering rock after leaching through upper weathered layers. Also some clay minerals are formed by hydrothermal activity. Adjei (2009).

Clay deposits may be formed in place as residual deposits, but thick deposits usually are formed as the result of a secondary sedimentary deposition process after being eroded and transported from their original location of formation. Clay deposits are typically associated with very low energy depositional environments like large lake and marine deposits. Chandler (1967).

The word clay is therefore among the more troublesome of the single-syllable words. It covers a huge range of natural substances differing greatly in appearance, texture, chemical and physical properties. Chandler (1967) justifies this by commenting that, "The justification for applying a single generic name to all of them is that they have certain important qualities in common. They are all plastic when wet, when dried they are all rigid, but will regain their plasticity when thoroughly rewetted; when fired they all become permanently non plastic and mechanically stronger".

2.3 Refractories

A refractory is a material that retains its shape and chemical identity when subjected to high temperature and is used in applications that require extreme resistance to heat. Raw materials used by refractory manufacturers almost all occur naturally but they are processed in several ways to lower the fluxes, unwanted oxides as much as possible. The principle raw materials used in the production of refractories are: the oxides of silicon, aluminum, magnesium, calcium and zirconium and some non-oxide refractories like carbides, nitrides, borides, silicates and graphite (www.PDHcenter.com).

The main types include fire-clay bricks, castables, ceramic fiber and insulating bricks that are made in varying combinations and shapes of diverse applications, (Bhatia, 2011).

The general requirements of a refractory material are;

1) Its ability to withstand high temperatures and trap heat within a limited area like a furnace
2) Its ability to conserve heat
3) Its ability to withstand load at service conditions
4) Its ability to withstand action of molten metal, hot gasses and slag erosion etc
5) Its ability to resist contamination of the material with which it comes into contact
6) Its ability to maintain sufficient dimensional stability at high temperatures and after/during repeated thermal cycling (Bhatia,2011),

The chemical and physical properties of a refractory product are characteristics which give an indication of the product's performance under specific operating conditions (i.e slagging, load bearing, fluctuating high temperatures, etc).

The significant physical properties include: Modulus of Rapture at room temperature, Bulk density, porosity, cold crushing strength, and elevated temperatures, reversible thermal expansion, permanent linear change (after reheating to specific temperatures), load subsidence or creep, thermal conductivity, abrasion resistance, thermal shock resistance, (Bhatia,2011).

Bhatia writes that refractories are used by the metallurgy industry in the internal linings of furnaces, kilns, reactors and other vessels for holding and transporting metal and slag and in non-metallurgical industries the refractories are mostly installed on fired heaters, hydrogen reformers, ammonia primary and secondary reformers, cracking furnaces, incinerators, utility boilers, catalytic cracking units, coke calciner, sulfur furnaces, air heaters, ducting, stacks, etc.

A majority of the above listed equipment operate under high pressure and operating temperature can vary from very low to very high (approximately 482.22^0C to 1593.33^0C). Refractories can be classified on the basis of chemical composition, end use and methods of manufacture as shown in Table 2.1.

Table 2.1: Classification of refractories based on chemical composition

Classification Method	**Examples**
Chemical Composition	
ACID REFRACTORIES are those which readily combines with bases. These are used areas where slag and atmosphere are acid	Silica, Semisilica, Aluminosilicate
BASIC REFRACTORIES are those which consists mainly of metallic oxides that resist the action of bases. These refractories are of considerable importance for furnace linings where the environment is alkaline; for example non-ferrous metallurgical operations.	Magnesite, Chrome-magnesite, Magnesite-chromite, Dolomite
NEUTRAL REFRACTORIES are those which do not combine with acids or bases. These are used areas where slag and atmosphere are either acidic or basic.	Fireclay bricks, Chrome, Pure Alumina
SHAPED REFRACTORIES are those which have fixed shaped when delivered to the user. These are what we call bricks. Brick shapes maybe divided into two: standard shapes and special shapes. Standards shapes have dimension that are conformed to by most refractory manufacturers and are generally applicable to kilns and furnaces of the same type. Special shapes are specifically made for particular kilns and furnaces. This may not be applicable to another furnaces or kiln of the same type. As a type they are almost always machine-pressed, thus, high uniformity in properties are expected. Special shapes are most often hand-molded and are expected to exhibit slight variations in properties.	Carbon, Silicon Carbide, Zirconia
End use	Blast furnace casting pit
Method of manufacture	Refractories can be manufactured in either of the following ways. Dry press process, fused cast, hand moulded, formed normal, fired or chemically bonded, unformed (monolithics, plastics, ramming mass, gunning castable, spraying)
Firing temperature	1250^{0}C and above

Types of Refractory

Fireclay Refractories: Fireclay refractories, such as fire-clay bricks, siliceous fireclays and aluminous clay refractories consist of aluminum silicates with varying silica (SiO_2) content of up to 78% and Al_2O_3 content of up to 44%. This type of refractory bricks is the most multipurpose, least costly of all the refractory bricks and is extensively used in the iron and steel industry, nonferrous metallurgy, glass industry, pottery kilns, cement industry, and by many others.

The total ranges of the properties of fire clay bricks are quite broad. American Society for Testing and Materials (ASTM) subdivides fire-clay brick into four major classifications depending primarily upon fusion temperature (Pyrometric Cone Equivalent, PCE) which, within limits, is a function of the alumina-silica ratio. The four standard classes of fireclay brick are: super duty, high-duty, Intermediate -duty, low-duty, and also semi-silica. These classes cover the range from approximately 18% to 44% alumina, and from about 50% to 80% silica. From the standpoint of fusion temperature, super duty fire-clay brick have a Pyrometric Cone Equivalent (PCE) of approximately Cone 33, which corresponds to 1745°C. This does not mean that a brick with a PCE of Cone 33 can be used in furnaces operating at 1745°C. On the contrary, it means that at this temperature in a clean, slag free, neutral to slightly oxidizing atmosphere, this brick would be unable to support its own weight.

The Table 2.2 shows that the melting point of fireclay brick decreases with decreasing amount of Al_2O_3 and increasing quantity of impurities.

Table: 2.2: Properties of typical fireclay bricks

Brick type	**%SiO_2**	**%Al_2O_3**	**% other constituents**	**PCE ^0C**
Super Duty	49-53	40-44	5-7	1745-1760
High Duty	50-80	35-40	5-9	1690-1745
Intermediate	60-70	26-36	5-9	1640-1680
High Duty (Siliceous)	65-80	18-30	3-8	1620-1680
Low Duty	60-70	23-33	6-10	1520-1595

Adapted from Bureau of Energy efficiency (2005)

High alumina refractories: Alumina silicate refractories containing more than 45% alumina are generally termed as high alumina materials. The alumina concentration ranges from 10 to 45%. Alumina is one of the most chemically stable oxides known, which offers excellent hardness, strength and spalling resistance. It is insoluble in water and super heated steam, and in most inorganic acids and alkalis. Alumina refractories carry the all purpose characteristics of fire-clay brick into higher temperature ranges that makes it suitable for lining furnace operating up to 1843.3°C. It has a high resistance in oxidizing and reducing atmosphere and is extensively used in heat processing industries. The refractoriness of high alumina refractories increases with increase in alumina percentage. The 50%, 60%, 70% and 80% alumina classes contain their respective alumina contents with an allowable range of ± 2.5%. High-alumina brick are classified by their alumina content according to the following ASTM convention. These are:

a) **Mullite refractory**: Mullite brick is about 72% alumina with 28% silica. These have excellent volume stability and strength at high temperatures. They are highly suitable for electric furnace roofs, blast furnaces and blast furnaces stoves, and the superstructure of glass tank furnaces.

b) **Corundum refractories-** The 99% alumina class of refractories is called corundum. These refractories comprise single phase, polycrystalline, and alpha-alumina.

High alumina bricks are most commonly used in cement, lime and ceramic kilns, glass tanks and crucibles for melting a wide range of metals, hearth & shaft of blast furnaces and in lead drossing furnaces. Studies indicate that these are very economical for the lower sections of soaking pits in the steel industry, primarily because of their resistance to iron oxide slags. Manufacturing cost and, therefore, price of these brick increase more rapidly with percentage alumina content, so it is essential to determine experimentally or by test installations the most economical alumina content for each service.

Silica brick: Silica brick (or Dinas) is a refractory that contains at least 93% SiO_2. The raw material is quality rocks. Various grades of silica brick have found extensive use in the iron and steel melting furnaces and the glass industry. In addition to high fusion point multi-type refractories, other important properties are their high resistance to thermal shock (spalling) and their high refractoriness. The outstanding property of silica brick is that it does not begin to soften under high loads until its fusion point is approached. This behaviour contrasts with that of many other refractories, for example alumina silicate materials, which begin to fuse and creep at temperatures considerably lower than their fusion points. Other advantages are flux and stag resistance, volume stability and high spalling resistance.

Magnesite: Magnesite refractories are chemically basic materials, containing at least 85% magnesium oxide. They are made from naturally occurring magnesite ($MgCO_3$). The properties of magnesite refractories depend on the concentration of silicate bond at the operating temperatures. High quality magnesite results from a CaO-SiO_2 ratio of less than two with a minimum ferrite concentration, particularly if the furnaces lined with the refractory operate in oxidizing and reducing conditions. The slag resistance is very high particularly to lime and iron rich slags.

Chromite refractories: Two types of chromite refractories are distinguished namely; Chrome-magnesite refractories, which usually contain 15-35% Cr_2O_3 and 42-50% MgO. They are made in a wide range of qualities and are used for building the critical parts of high temperature furnaces. These materials can withstand corrosive slags and gases and have high refractoriness. The other type is Magnesite-chromite refractories, which contain at least 60% MgO and 8-18% Cr_2O_3. They are suitable for service at the highest temperatures and for contact with the most basic slags used in steel melting. Magnesite-chromite usually has a better spalling resistance than chrome-magnesite.

Zirconia refractories: Zirconium dioxide (ZrO_2) is a polymorphic material. It is essential to stabilize it before application as a refractory, which is achieved by incorporating small quantities of calcium, magnesium and cerium oxide, etc. Its properties depend mainly on the degree of stabilization, quantity of stabilizer and quality of the original raw material. Zirconia refractories have a very high strength at room temperature, which is maintained up to temperatures as high as 1500^0C. They are therefore useful as high temperature construction materials in furnaces and kilns. The thermal conductivity of zirconium dioxide is much lower than that of most other refractories and the material is therefore used as a high temperature insulating refractory. Zirconia exhibits very low thermal losses and does not react readily with liquid metals, and is particularly useful for making refractory crucibles and other vessels for metallurgical purposes. Glass furnaces use zirconia because it is not easily wetted by molten glasses and does not react easily with glass.

Oxide refractories (Alumina): Alumina refractory materials that consist of aluminium oxide with little traces of impurities are known as pure alumina. Alumina is one of the most chemically stable oxides known. It is mechanically very strong, insoluble in water, super heated steam, and most inorganic acids and alkalies. Its properties make it suitable for the shaping of crucibles for fusing sodium carbonate, sodium hydroxide and sodium peroxide. It has a high resistance in oxidizing and reducing atmosphere. Alumina is extensively used in heat processing industries. Highly porous alumina is used for lining furnaces operating up to 1850^oC.

Monolithicsin: Monolithic refractories are single piece casts in the shape of equipment, such as a ladle. They are rapidly replacing the conventional type fired refractories in many applications including industrial furnaces. The main advantages of monolithics are:

-Elimination of joints which is an inherent weakness.

-Faster application method.

-Special skill for installation not required.

-Ease of transportation and handling.

-Better scope to reduce downtime for repairs.

-Considerable scope to reduce inventory and eliminate special shapes.

-Heat savings.
-Better spalling resistance.
-Greater volume stability.

Monolithics are put into place using various methods, such as ramming, casting, gunniting, spraying, and sand slinging. Ramming requires proper tools and is mostly used in cold applications where proper consolidation of the material is important. Ramming is also used for air setting and heat setting materials. Because calcium aluminate cement is the binder, it will have to be stored properly to prevent moisture absorption. Its strength starts deteriorating after 6 to 12 months.

2.4 Firing

Much has been done on ball clay but little on ant-hills and there is no available literature on developing a refractory material out of ant-hill clays and as a result there is no literature on firing profile for ant-hill clays. A lot more has been done on ball clay and the heating profile are well defined for instance according to Goffer, (2007) Firing is heating a material to high temperatures, above about 600^0C. Heat supplied during the firing process provides sufficient energy to dislodge atoms from their positions from the clay and cause them to migrate to more favorable sites; the final result of the firing process is that the clay is converted to a new hard and rigid ceramic material that is stable to water, high temperature and weathering.

Firing of clays leads to the alteration of physical properties, chemical and mineralogical properties of the constituents in the body for instance the case of porcelain. Fired bodies are permanently hardened if firing is done appropriately to the characteristics of the material used to make the clay products, (en.wikipedia.org/wiki/pottery).

According to Goffer, (2007), the changes caused by heat on wet clay are indicted in Table 2.3.

Table 2.3: The changes caused by heat on wet clay

Temperature (^{0}C)	**Change**
Room temperature – 100	Drying (loss of water formation).
100 – 500	loss of water plasticity.
500 – 600	Dehydration (loss of chemically combined water and modification of clay structure).
600 – 900	Breakdown of clay structure and incipient verification.
900 – about 1700	Verification and formation of new structures.
Above 1700	Melting.

Adopted from Goffer, (2007)

Also during the firing process, a variety of reactions take place. Carbon-based impurities burnout, chemical water evolves (at 100^0C to 200^0C) and carbonates and sulfates begin to decompose (at 400^0C to 700^0C). Gasses are produced which must escape from the ware. On further heating, some of the minerals break down into other phases, and the fluxes present (feldspar, and flint) react with the decomposing minerals to form glasses (at 700^0C to 1100^0C). After the desired density is achieved (at greater than 1200^0C), the ware is cooled, which causes the liquid glass to solidify, thereby forming a strong bond between the remaining crystalline grains. After cooling, the porcelain is complete, (www.madehow.com).

2.5 Modulus of Rupture

Modulus of Rupture, frequently abbreviated as MOR, (sometimes referred to as bending strength), is a measure of a specimen's strength before rupture. It can be used to determine a wood species' overall strength. MOR is expressed in mega paschal (MPa). The modulus of rupture (MOR) is an important variable in the characterization of refractory materials. Determination of the maximum load at high temperatures is a property which, along with other thermo physical properties, is an important parameter for quality control and development of furnace linings.

The modulus of rupture is determined as follows: A sample is placed between two supports with a specified distance between them (span) as shown in figure.2.1. The testing machine applies a load at a specified rate to the centre of the sample until the sample breaks. The MOR expressed in mega-Pascal (MPa), is calculated using the load at which the sample failed, the span between the supports, and the cross-section of the sample.

$$\mathrm{MOR} = 3NL/2wd^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.1$$

Where,

N = load at rupture,
L = distance between supports (span),
w = width of the specimen and
d = thickness of the specimen

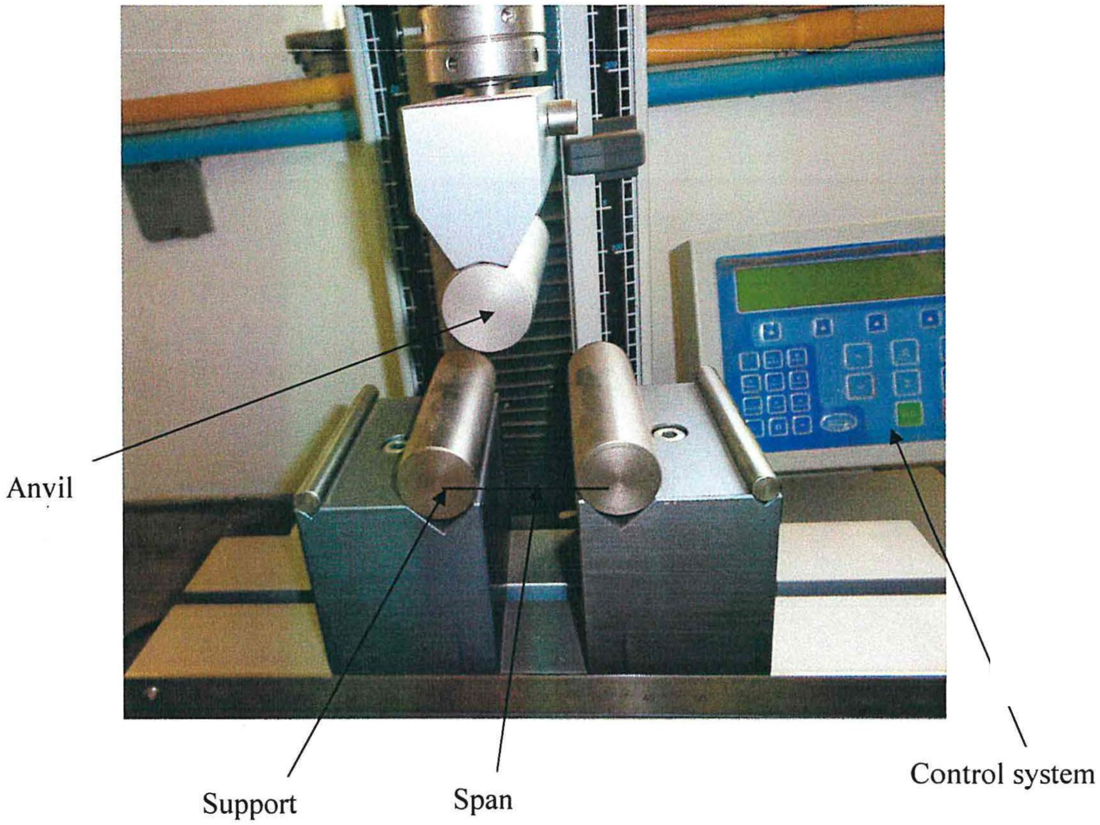

Figure: 2.1. The three point loading machine

According to Singer (1963) modulus of rupture can be deduced from the result by the formula;

$$\mathrm{MOR} = 3wl/2bh^2 \ldots\ldots\ldots\ldots\ldots 2.2$$

Where,

w = weight required to break bar, L = distance between supports, b = width of the bar, h = height of the bar (for rectangular specimen).

The result is expressed in Mega pascal.

All BNZ insulating refractory fire bricks manufactured from USA according to ASTM requirements are made from high purity refractory clays and other ceramic materials and their MOR ranges between 965Kpa and 2068Kpa with heating temperatures ranging from 1260^0C to1760^0C (www.armilcfs.com).

2.6 Previous work done of chemical analysis on ant-hills in other parts of the world

A study on ant-hills clay carried out by Adepegba and Adegoke (1974) in Nigeria confirmed that termites do actually stabilize the soil before use. An extract of the brown acidic substance of soldier termites was analyzed and this showed that the organic substance was a mixture of acetic 2- amino glucose and protein, both being hydrolysis products of chitin and proctodael matter. This substance supports cementations and similar to the acetic secretion of soldier termites.

Also a study on Identification, extraction and characterization of chemical compounds carried out by Fugro Consultants Nigeria limited showed that ant-hills contains 11.6 (mg/kg) of TOM; 15.9 (mg/kg) of Magnesium, 11690 (mg/kg) of Iron and 23.3 (mg/kg) of extractable Chloride which are responsible for structural stability of ant-hills. The result also revealed that increase of clay content enhances the structural stability of ant-hills

Table 2.4: Chemical analysis by Adepegba & Adegoke (1974)

Parameter	**Ant-hill (A)**	**Clay soil (C)**	Termite added (A-C)
PH (H_2O)@250c	6.61	6.93	-0.32
Density	1.14	1.46	-0.02
TOM(g/kg)	11.60	4.50	7.10
Phenol(mg/kg)	6.24	6.95	0.71
Calcium(m/kg)	51.90	109.00	-57.10
Magnesium(mg/kg)	15.90	12.20	3.70
Potassium(mg/kg)	808.00	1023.00	-215.00
Aluminium(mg/kg)	7104.00	7968.00	-864.00
Iron(mg/kg)	11690.00	7701.00	3989.00
Extractable Chloride(mg/kg)	23.30	14.00	9.30
Extractable sulphate(mg/kg)	50.00	50.00	0.00
Extractable Phosphate(mg/kg)	0.78	0.85	-0.07

CHAPTER THREE: METHODOLOGY

3.0 Introduction

This chapter outlines the various procedures used during the study. The procedures include: Research design, sampling and sampling technique, sample preparation, sample forming methods, sample firing, experimental measurement during chemical analysis and modulus of rupture tests.

3.1 Research Design

The exploratory and descriptive designs were adopted during the study. Here a variety of dimensions and heating temperatures were used to test how the ant-hill clay behaves during formation and firing. Quantitative study was also used to observe and examine the phenomena during the study.

3.2 Sampling and Sampling Technique

Systematic sampling technique was employed in sampling the ant-hill clays that were used during the study. The choice of the samples was based on the upland ant-hills from the selected parts of the country. The samples were picked from three geographical sites with GPS coordinates as shown in the map of Uganda below. The three geographical sites were Nkombe village in Mayuge district with GPS coordinates: latitude $0^0$28'1.43"N (0.467063) and longitude $33^0$23'23.98"E (33.389993), Namagunga village in Mukono district with GPS coordinates: latitude $0^0$22'13.91"N (0.370530) and longitude $32^0$52'59.91"E (32.883309) and Kyambogo University in Kampala District with GPS coordinates: latitude $0^0$20'41.88''N (0.344966) and longitude $32^0$37'31.08''E (32.62530) in Uganda. From each geographical site three ant-hills were selected and were within a distance 500m from each other. The samples from Nkombe village were labeled A, the sample from Namagunga were labeled B and samples from Kyambogo University were labeled C.

Below is the map showing sampling geographical sites for the study.

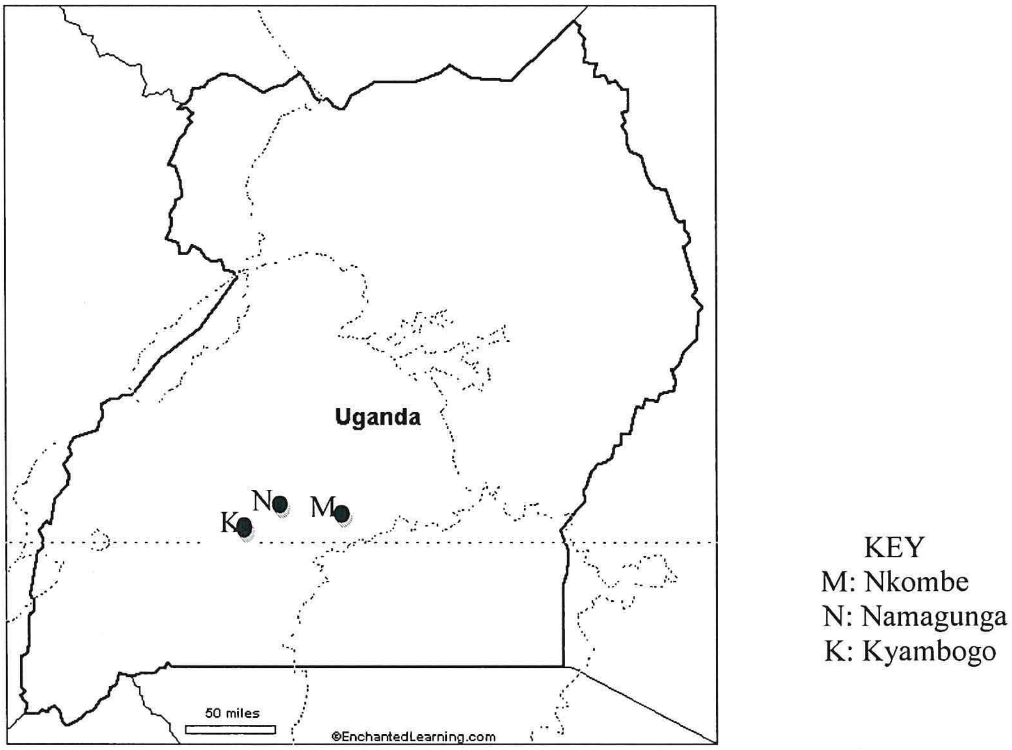

Figure 3.1: A map of Uganda showing the three geographical sites

3.3 Sample Preparation

From each ant-hill a mass of 33kg was extracted, mixed together and crushed in order to obtain a homogeneous mixture of 99kg from the three anti-hills from each geographical site. The uniform mixture was soaked in 40litres of water for 120hrs to enable the roots and sand to settle at the bottom of the container. After 120hrs sieving was done to remove the roots and sand using 6 different sieves in stages starting with one of 425µm followed by 200µm then 125µm, 75µm, 53µm and finally 45µm. After sieving the clay- water mixture was left to settle down for a period of 72hrs and after which the water was decanted. The remaining smooth slip was poured in into molds of plaster of paris in order to further reduce the moisture content for a period of 168hrs. The soft clay removed from the plaster of paris was dried normally under the sun. The dry clay obtained was milled and sieved into fine powder which was subjected to the three forming methods.

3.4 Sample Forming methods

3.4.1 Dry Pressing

From each of the samples, 150g of the dry fine powder was weighed off and then compacted by 7 different pressures of 57.669Mpa 61.788Mpa, 65.908Mpa, 70.027Mpa, 74.146Mpa, 78.265Mpa and 82.385Mpa using hydraulic press machine shown in Figure 3.2 to form a brick of dimensions 109.6mm x44.3mm x 10.9mm.

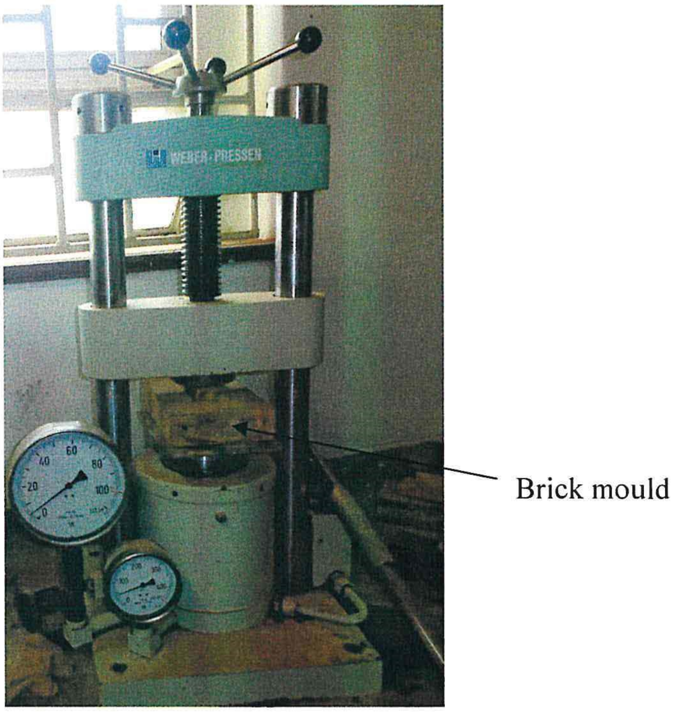

Figure 3.2 Hydraulic Press with a die mould (Hydraulina laboratory manual press-PW40)

Of all the compacted samples formed, 70% were successfully retrieved and 30% of the samples developed cracks and strata (as shown in Figure 4.3) and all warped after firing as shown in Figure 4.6. The dry pressing forming method was therefore abandoned then the slip casting and wet compressing methods adopted.

3.4.2 Slip casting

From each of the samples, 1000g of the dry powder was weighed off, then 600ml of water added and left for 15hours to dissolve without agitating it to form a very thick slip. The thick slip was then put into the molds at room temperature and covered with white plain papers to reduce on the loss of moisture to the surrounding and left in the molds for 72 hours, after which the bricks were removed from the molds and left to dry under room temperature for 7 days before firing in the kiln. The bricks formed were of dimensions 132.7mm x 33.4mm x 32.7mm as shown in Figure 4.4.

3.4.3 Wet Pressing

From each of the samples, 100g of the dry powder was weighed off and mixed with 10ml of water. This was then compacted to a pressure of 18.972Mpa to form a brick of dimensions 111.2mm x 47.4mm x 10.4mm shown in Figure 4.5 using a hydraulic press machine shown in Figure 3.2.

The brick sample was then allowed to dry under room temperature for 48 hours before firing in the kiln.

3.5 Sample Firing

The compressed bricks were placed in an electric furnace at a temperature of 21^0C, which is room temperature. The samples were then fired at a rate of 120^0C/hour (2^0C /minute) to a temperature of 543^0C to avoid cracks in the sample which would be caused by escaping moisture. This temperature was maintained for 1 hour in the furnace, this helped to remove the remaining water from the sample. After all the excess water had been removed the samples were then fired to a temperature of 950^0C at a heating rate of 360^0C /hour (6^0C /min) and held at this temperature for 30 minutes before switching off the furnace. The holding time of 30 minutes is supposed to improve the microstructure, mechanical and dielectric properties of the samples. The samples cooled down inside the furnace to 21^0C. The samples were then retrieved from the furnace but had cracks and were brittle as shown in the Figure 4.6. When the above heating profile was used on the brick samples formed by wet pressing and slip casting methods, all developed cracks after firing and were brittle as shown in Figure 4.7 and Figure 4.8.

The firing profile was then changed in the second run and the sample bricks formed by wet pressing method were placed in an electric furnace at a temperature of 21^0C. The samples were then fired at a rate of 400^0C/hour to a temperature of 1150^0C and held for 1 hour before switching off the furnace. Samples from Nkombe were successfully retrieved but samples from Namagunga and Kyambogo had cracks and curved as shown in Figure 4.9.

The firing profile was again changed for the third run and the sample bricks formed by wet pressing and slip casting method which were first dried in air were placed in an electric furnace at a temperature of 150^0C and held for 5minutes. This was done to remove the remaining water from the samples. The samples were then fired at a rate of 120^0C /hour (2^0C /minute) to a temperature of 534^0C and held at this temperature for 1 hour in the furnace. After the excess water had been removed the samples were then fired to a temperature of 1150^0C at a heating rate of 360^0C /hour (6^0C /min) and held at the top temperature for 1 hour before switching off the furnace and samples allowed to cool down in the furnace at a rate of 5^0C/ minute. All the fired samples obtained were crack free as shown in Figure 4.10 and Figure 4.11. The electric furnace used at Uganda Industrial Research Institute could not go beyond a temperature of 1150^0C. This explains why the maximum firing temperature was 1150^0C.

3.6 Experimental Measurement

3.6.1 Procedure for the determination of pH of the ant-hill clay.

A mass of 10.0g of each of the air dried sample of the ant-hill clay were weighed into separate plastic beaker and 25ml of distilled water were added (1:2.5, wt:v). The mixture was stirred thoroughly with a glass rod and allowed to stand for 30minutes. The pH meter electrode was then inserted into the supernatant of the settled suspension as shown in the Figure 3.3 and the pH values were then recorded after 3 minutes as shown in the Table 4.2.

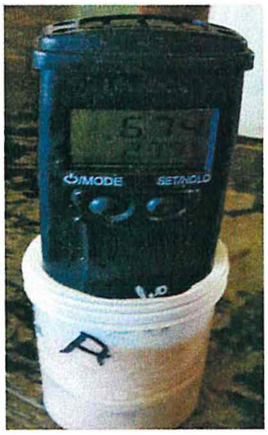

Figure 3.3: PH Meter readings in the one of the sample

3.6.2 Procedure for determination of the amount of Potassium, Sodium and Calcium present in the ant-hill clay

A mass of 0.50g from each of the three samples was separately introduced into a digestion tube and digested.

The process of digesting (also known as wet ashing) involves adding a digesting mixture:(Concentrated sulphuric acid + selenium powder + lithium sulphate + hydrogen peroxide) to the weighed ant-hill clay samples in a digestion tube and the mixture placed into a pre-heated block digester at 150^0C. The heating is continued up to a temperature of 350^0C then held for at least two hours until the mixture digest turned to a white colour which indicates the end of digestion as shown in Figure 3.4.

The digest was allowed to cool and diluted with distilled water to 50mls. From this diluted digest aliquots were removed to determine the concentration of K, Na, and calcium. The Flame photometer was used to read the emissions of Sodium, calcium and potassium as shown in Figure 3.5. The instrument was standardized with a blank solution which contained no metal. Standards were aspirated first followed by the digests which contained the metal ions to be determined. The concentration of Sodium, calcium and potassium in the ant-hill clay samples were determined by using the equations;

$$Concentration = \frac{absorption}{atomic\ masss} \times \frac{50}{weight} \times 10 \quad ......3.1$$

The calculated concentration values obtained were recorded as shown in Table 4.4. These values were used to determine the concentration for the oxides of Potassium (K), Sodium

(Na) and Calcium (Ca) in the ant-hill clay samples by multiplying them with their corresponding converting factor as shown in Table 4.5.

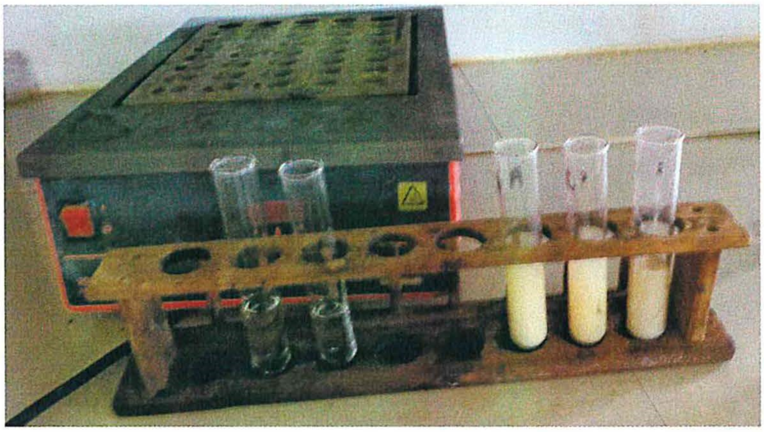

Figure 3.4 Mixture Digest

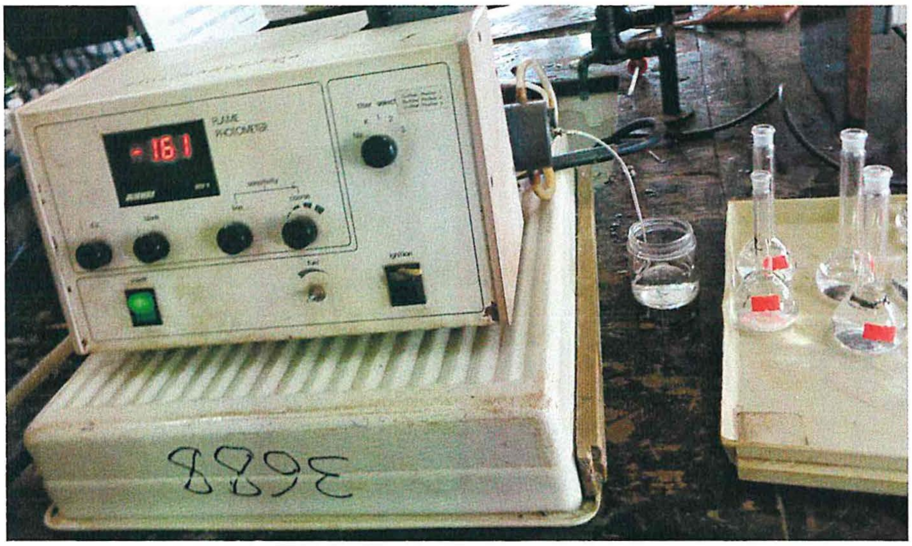

Figure 3.5: A flame photometer with sample solution

3.6.3 Procedure for determination of heavy metals present in the ant-hill clay

The concentration of Cu, Fe, Zn, Mn and Mg were determined using Atomic absorption spectrometer (GBC SavantAA) as shown in Fig 3.6

The method involved the preparation of the working standards of the metal. The wavelength of the metal was selected and the apparatus was standardized with blank solutions which contained no metal. Standard were aspirated and the absorbance was used to prepare a calibration curve. The samples were also aspirated, after which the machine gave direct concentrations which were multiplied with the dilutions to obtain actual concentrations as shown in Table 4.6.

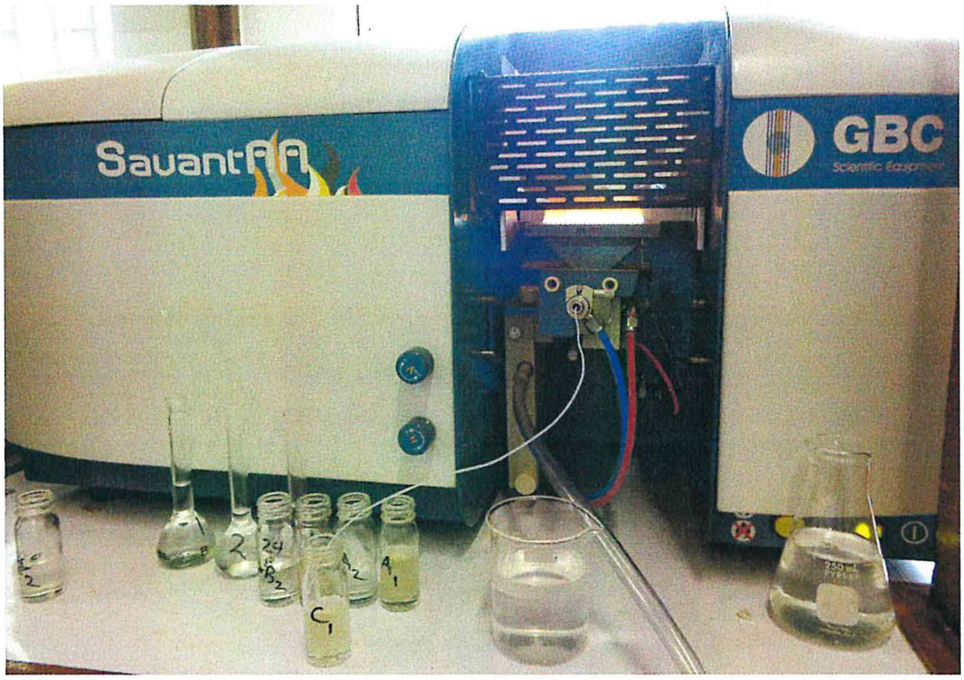

Figure 3.6: Atomic Absorption Spectrophotometer (GBC SavantAA) with sample solution.

3.6.4: Determination of Alumina, Silica, Iron Oxide and Phosphate present in the ant-hill clay

The ant-hill clay samples from the three geographical sites were crushed and pulverized to 180 mesh size and then subjected to chemical analysis test using An X-Ray Spectrometry shown in Figure 3.7. The percentage of the element present in each sample was obtained and recorded as shown in Table 4.7.

Figure 3.7: An X-Ray Spectrometry loaded with samples.

3.6.5 Procedure for determination of the amount of Organic Carbon present in the ant-hill clay

A mass of 0.5g of each of the three ant-hill clay samples was mixed with Potassium dichromate after which Sulphuric acid was added. This was followed by heating up to a temperature of 151^0C after which it was allowed to cool. This was done in order to complete the oxidation of the carbon in the ant-hill clay by the dichromate. The excess Potassium dichromate was titrated against ferrous sulphate with ferroin being the indicator. This was carried so as to obtain data consisting of the initial volume (V_0) and final volume (V_f) as shown in Table 4.8. The value obtained was used for calculating the percentage of carbon present in the ant-hill clay using the equation;

$$\textit{Percentage of Organic carbon (\% C)} = \frac{T \times 0.3 \times 1.12}{Weight} \qquad \ldots\ldots\ldots\ldots\ldots\ldots 3.4$$

Where T is the difference between the volume of the blank and the sample volume, 1.12 is morality of Fe_2SO_4 and 0.3 is a constant. The calculated values were recorded as shown in Table 4.9. The method also involved the preparation of the working blanks.

The Percentage of total organic matter (TOM) present in the ant-hill clay was also determined by multiplying the Percentage of Organic carbon with 1.72 as shown in Table 4.10.

3.6.6 Procedure for determination of the amount Nitrogen (N) present in the ant-hill clay

A volume of 5 mls was removed from the diluted digest and placed in a distillation unit to distill off the Nitrogen contained in the ant-hill clay as shown in the Fig 3.8. This was done by adding Sodium hydroxide and trapping the Ammonia in Boric acid which was later titrated against standard hydraulic acid, data obtained as shown Table 4.11 was used for calculating the Nitrogen content present in the ant-hill clay using the equation;

$$Percentage\ of Nitrogen \quad = \quad \frac{\left[\frac{V \times 0.005}{1000} \times 14 \times 5\right]}{Weight} \times 100 \qquad \ldots\ldots\ldots\ldots\ldots\ldots 3.5$$

Where;

V= Difference in the titre values,

0.005= the molarity of the acid,

14 = atomic weight of nitrogen and

5 = the dilution factor

Figure 3.8: Distillation unit to distill off the Nitrogen

3.7 Modulus of Rupture

Sixteen fired samples from each geographical site formed by both wet pressed and slip casted methods were selected and subjected to the modulus of rupture test. The modulus of rupture was determined using the three point loading machine (LLOYD INSTRUMENTS) shown in Figure 3.9.

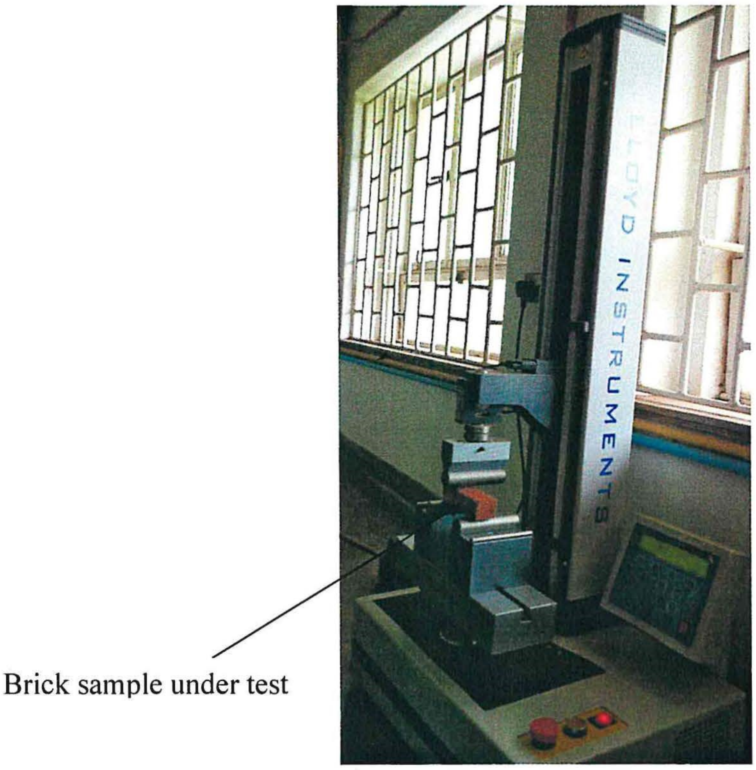

Figure3.9: The three point loading machine with a sample brick under test (LLOYD INSTRUMENTS).

The testing load was applied centrally to the sample until the sample broke. The load at rupture of each sample of known dimensions was recorded as shown in the Tables A1 – A5 (see Appendix 1). Each brick from each geographical site was subjected to the MOR test from which an average modulus of rupture for the samples was determined as shown in Tables 4.12 and Tables 4.13.

The MOR of each sample was determined by using the formula

$$MOR = 3NL/2wd^2; \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

Where,

N = load at rupture in newtons, L= distance between supports in meter (span) =0.1m, w = width of the specimen in meters and d = thickness of the specimen in meters.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.0 Record of Results

The samples from the three geographical sites were weighed and their masses were recorded as shown Table 4.1.

Table 4.1: Mass of the ant-hill clay samples

SAMPLES	A	B	C
MASS (gm)	0.476	0.491	0.452

The chemical analysis for all the samples was carried out and composition results were recorded as shown in the various tables.

Table 4.2: PH Results obtained for the ant-hill clay.

SAMPLES	A	B	C
PH VALUES	6.74	5.56	5.50

Sample (A) from Nkombe had a high PH value than that from Namagunga and Kyambogo as shown in Table 4.2. The high PH in sample A could be due to presence of more potassium in sample A than samples B and C as shown in Table 4.5

Table 4.3: Results obtained for K, Na and Ca in upland ant-hill clay.

SAMPLES	K ±0.1 (mg)	Na ± 0.1 (mg)	Ca ± 0.1 (mg)
A	136.0	75.0	33.0
B	19.0	42.0	23.0
C	17.0	28.0	17.0

The concentration of Potassium, Sodium and Calcium in the ant-hill clay samples was determined by using equation 3.1 in chapter three and recorded as shown in Table 4.4. The Values obtained were further used in the determination of the concentration of the respective oxides as shown in Table 4.5.

Table 4.4: Concentration of K, Na and Ca in the ant-hill clay

SAMPLES	K ± 0.01 (mg/Kg)	Na ± 0.01 (mg/Kg)	Ca ± 0.01 (mg/Kg)
A	7190	4170	3490
B	1230	2860	2970
C	1030	1780	2050

Table 4.5: Results obtained for the oxides of K, Na and Ca in the ant-hill clay

PARAMETER	SAMPLE	CONCENTRATION (ppm)	% COMPOSITION
K_2O	A	8670	0.867
	B	1480	0.148
	C	1240	0.124
Na_2O	A	4310	0.431
	B	2960	0.296
	C	1840	0.184
CaO	A	4880	0.488
	B	4160	0.416
	C	2870	0.287

The level of K_2O, Na_2O and CaO were greater in Samples A and lower in sample C.

Table 4.6: Results obtained for the heavy minerals in the ant-hill clay by AAS

PARAMETERS		SAMPLE READING ± 0.001 (μg/ml)	BLANK READING ± 0.001 (μg/ml)	SAMPLE – BLANK (Y) (μg/ml)	FINAL CONC. ppm(mg/Kg)	Percentage Composition
MgO	A	0.409	0.128	0.281	295.2	0.481
	B	0.393	0.128	0.265	260.7	0.431
	C	0.214	0.128	0.086	95.1	1.575
MnO	A	2.925	0.721	2.204	231.5	0.297
	B	4.156	0.721	3.435	349.8	0.452
	C	2.837	0.721	2.116	234.1	0.297
CuO	A	0.387	0.174	0.213	22.4	0.275
	B	0.524	0.174	0.350	35.6	0.451
	C	0.394	0174	0.220	24.3	0.300
ZnO	A	0.530	0.000	0.530	55.7	0.697
	B	0.888	0.000	0.888	90.4	0.112
	C	0.333	0.000	0.333	36.8	0.050

The level of Zn was greater in sample A and lower in sample C. Conversely, the concentration of Mg was greater in sample C than in sample A. There was no significant difference in the concentration of Mn and Cu in samples A and C. Sample B had greater concentration of Mn and Cu than the other samples.

Table 4.7: % Composition results of upland ant-hill clay bases on an X-Ray Spectrometry

SAMPLE	Sio_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	WO_3	ZrO_2	Cr_2O_3	Rb_2O	SrO
A	43.22	26.61	8.55	1.265	0.11	0.298	0.070	0.018	0.023	0.008
B	36.25	26.89	14.87	2.026	0.12	0.054	0.066	0.039	0.008	0.018
C	41.57	33.03	9.94	1.206	0.10	0.057	0.028	0.015	0.007	0.005

Sample A had greater level of silica, zirconium, wolfram (Tungsten) and rubidium than samples B and C. The alumina content was greater in sample C. Sample B was highly enriched in iron, titanium, chromium and strontium as compared to sample A and C.

Table 4.8: Primary data used in determination of Organic Carbon

SAMPLE	$V_0 \pm 0.1$ (ml)	$V_f \pm 0.1$ (ml)	$V_0 - V_f$ (ml)
A	10.0	12.9	2.9
B	12.9	14.8	1.9
C	14.8	17.2	2.4
BLANK: 1	17.2	20.9	3.7
2	20.9	24.4	3.5

Table 4.9: Percentage of Organic Carbon in the ant-hill clay

SAMPLES	$V_s \pm 0.1$ (ml)	T (ml)	% C
A	2.9	0.7	0.48
B	1.9	1.7	1.15
C	2.4	1.2	0.82
Blank Average	3.6		

The organic carbon content was about twice in Sample B. The total organic matter (TOM) content was also greater in sample B compared to other samples as shown in Table 4.10. TOM is responsible for binding the particles of the ant-hill together enhancing the cohesive force between the particles and thus the strength of the sample brick.

Table 4.10: Percentage of Total Organic Matter (TOM) in the ant-hill clay

SAMPLES	% C
A	0.83
B	1.98
C	1.41

Table 4.11: Results obtained for Nitrogen present in the ant-hill clay.

SAMPLES	$V_0 \pm 0.1$ (ml)	$V_f \pm 0.1$ (ml)	$V = V_f - V_0$ (ml)	% of Nitrogen
A	9.4	10.8	1.4	0.106
B	10.8	12.1	1.3	0.117
C	12.1	13.1	1.0	0.080

The level of nitrogen was low in sample C compared to the other samples.

The upland ant-hill clay recorded percentage composition results were further displayed on the bar charts for clarity as shown in Figures 4.1 and Figures 4.2

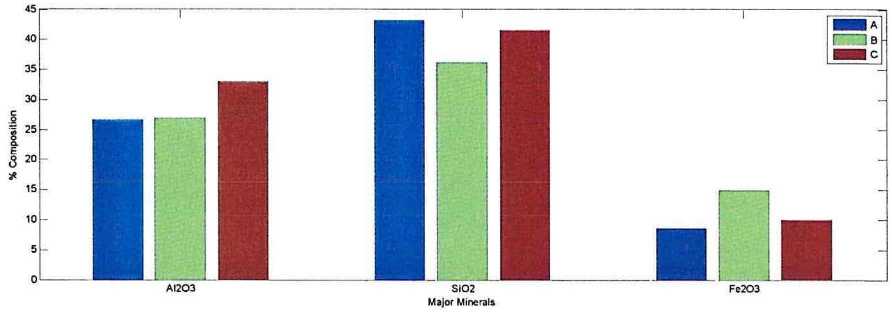

Fig 4.1: Bar chart comparing % composition of Major Minerals in upland Ant-hill clay

From the bar chart in Figure 4.1, sample A was rich in silica while sample B was rich in iron and C was rich in alumina. In Figure 4.2, it is observed that the percentage of titanium and total organic matter are high in upland ant-hill clay samples as compared to other minor minerals.

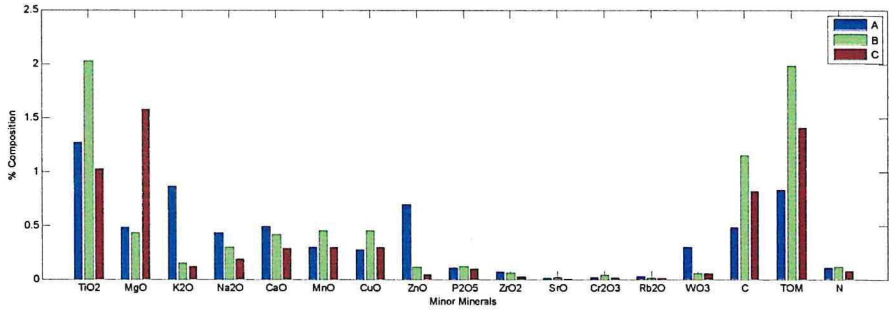

Fig 4.2: Bar chart comparing % composition of Minor Minerals in upland Ant-hill clay

4.1 Compression Results

During the dry compressing processes 30% of the samples failed and 70% were successfully retrieved. The samples which failed had developed strata (layers) along their length. This does not occur when ball clay is dry compressed according to Nassejja (2012). The development of strata could be attri Minor minerals compression which could not permit gradual escape of air from within the powder.

Below are some of the samples that were obtained by dry pressing forming method.

Figure 4.3 Dry compressed brick samples

When the method of forming was changed from dry compressing to wet pressing and slip casting all the samples were successfully retrieved. Some of the samples that were formed by the slip casting and wet pressing forming methods are shown in the Figure 4.4 and Figures 4.5.

Figure 4.4 Slip casted brick samples

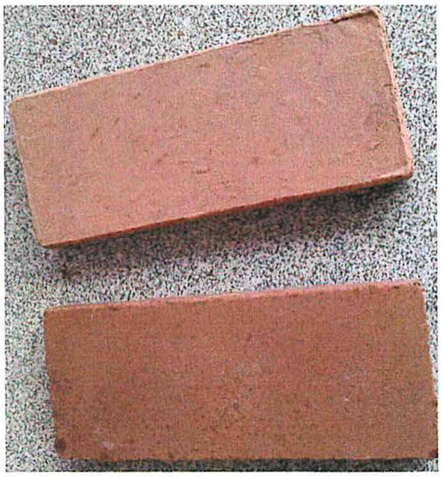

Figure 4.5 Wet compressed brick samples

4.2 Firing Results

In the first run, the dry compressed samples were subjected to the heating profile used for ball clay. All the dry compressed samples were found to be cracked and warped after firing. This showed that the heating profile for ant-hill clay is different from that of ball clay. This could be possible due to lower values of alumina, potassium and calcium in the ant-hill clay. These elements help ceramic materials in resisting thermal stress and thus reducing cracking and warping. Some of the samples had black cores suggesting difference in circulation of heat in the fired samples. Because of the above problem encountered, the use of dry compression process was abandoned and replaced by slit casting and wet pressing process.

Below are some of the fired samples which were formed by the three different forming methods using the first heating profile in chapter 3.5 (at a rate of 120^0C/hour to a temperature of 543^0C and then 360^0C/hour to 950^0C).

Figure 4.6: Dry pressed fired brick samples

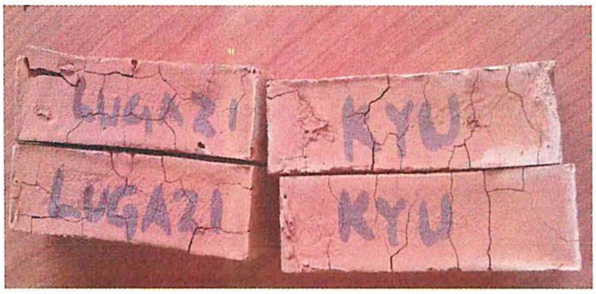

Figure 4.7 Slip casted fired brick samples

Figure 4.8 Wet compressed fired brick sample

In the second run, the heating profile was changed as mentioned in chapter 3 and Nkombe samples (sample A) were retrieved successfully but those for Namagunga (sample B) and Kyambogo(sample C) had cracks and were curved as shown in Figure 4.9.

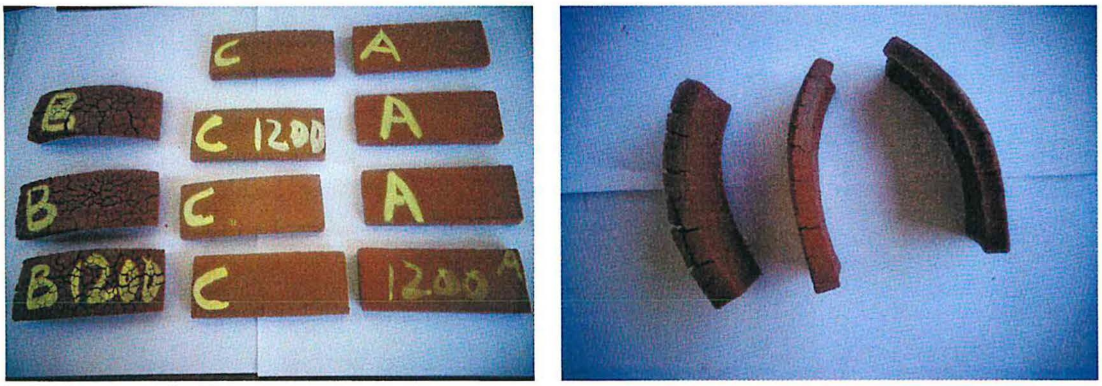

Figure 4.9 Fired brick samples in the second run

In the third run, the heating profile was changed as mentioned in chapter 3 and all the samples obtained were recovered without cracks or warping as shown in the Figures 4.10 and Figures 4.11.

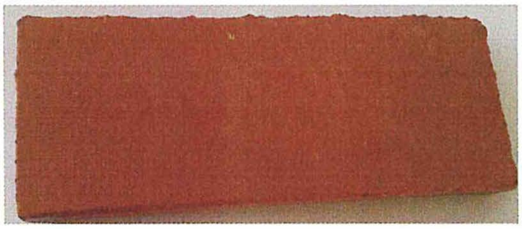

Figure 4.10 Wet pressed fired brick sample

Figure 4.11 Slip casted fired brick samples

When the samples were fired it was discovered that slip casted samples had more pores that wet pressed sample as shown in Figures 4.12 and Figures 4.13.

4.3 Modulus of Rupture Results.

All samples formed by dry pressing, cracked during firing, thus they were not subjected to MOR test.

Table 4.12: MOR of fired slip cast bricks

Samples	MOR(KPa) x10^{-2} Namagunga	MOR(KPa) x10^{-2} Kyambogo
1	3.88541	12.18508
2	2.17472	10.55290
3	3.00136	11.36899
4	2.17725	12.18508
5	3.84135	12.15804
6	2.77079	11.58695
7	3.88001	12.19302
8	3.54079	11.97241
Average±σ	**3.16002±0.83314**	**11.77836±0.68375**

Table 4.13: MOR of fired wet pressed slabs

Samples	MOR(KPa) Nkombe	MOR(KPa) Namagunga	MOR(KPa) Kyambogo
1	10253.1646	2289.8734	1766.9620
2	12132.9114	1671.2658	1298.7342
3	16917.7215	1980.5696	1532.8481
4	14679.0042	2007.2153	1500.6729
5	13945.2062	1994.7826	1429.2651
6	15028.4799	1836.8957	1532.8706
7	12839.0639	2110.3324	1477.5309
8	14813.0987	1816.5350	1542.9201
Average±σ	**13826.08±2340.01**	**1963.43±205.49**	**1510.23±153.83**

It was also found out that the unfired slip casted samples were homogeneous, densely packed particles thus improving the mechanical strength of the ceramic material. Fired slip casted samples of the ant-hill clay had a lot of pores due to the burning up of the hydro carbon embedded in the material. During the heating process the escaping gas from the hydro carbon caused the development of cracks which then led to overall weakness of the material as shown in Table 4.12.

The best forming method therefore, was wet pressing which gave high mean values of MOR for a fired sample (13.82608MPa for Nkombe, 1.96343MPa for Namagunga and

1.51023MPa for Kyambogo) as shown in Table 4.13. This was attributed to the reduction of coarse micro pores and macro pores during the wet pressing method, since pores have a great influence on the properties of ceramics and thus the need to be carefully controlled, Salib, (1990).

Wet pressed fired samples were found to be denser than the fired casted samples. Average density of wet pressed fired samples was 1860Kgm^{-3} while that of fired casted samples was 1640Kgm^{-3}. In wet pressed samples the separation between particles is reduced through compressing, the particles are forced to be close to each other resulting in a stronger bonding. As a rule in properties of matter, the denser the solid the stronger it is. This is supported by the high values of MOR which were obtained for wet compressed samples. It was also found out that thin (of thickness = 10.0mm) wet pressed samples had high values of MOR compared to the thicker (of thickness = 32.7mm) ones. Thicker samples have a tendency to form lots of pores of which a significant number are large pores while thinner samples have fewer and much small pores as evidenced by the cross sections of the thick and thin sample as shown in Figure 4.12 and Figures 4.13. This is because in the unfired samples the organic carbon is much more in a thicker sample than in the thin samples. The number of pores formed after firing is higher in the thicker samples.

Theory too supports this suggestion that modulus of rupture is inversely proportional to thickness of a ceramic material. Theory gives the MOR as; MOR = $3NL/2wd^2$, Where N = load at rupture in newtons, L= distance between supports (0.1m) in meters, w = width of the specimen in meters and d = thickness of the specimen in meters.

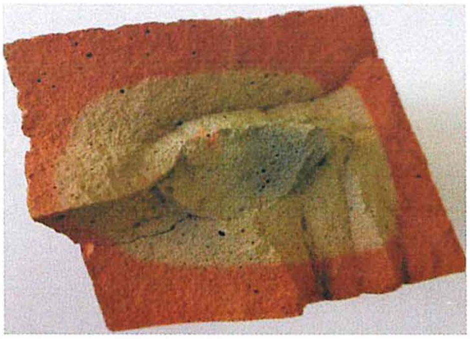

Figure 4.12: Pores in a thick fired brick sample

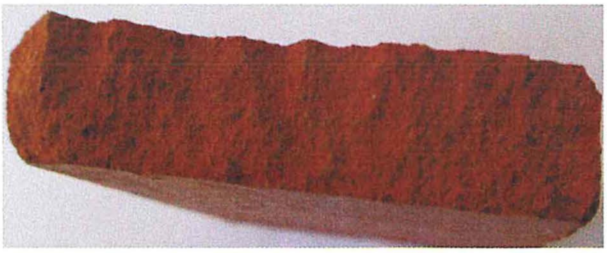

Figure 4.13 Pores in a thin fired brick sample

Wet pressed sample had few and smaller pores left after sintering. These pores were not destroyed during sintering in the casted samples. This is because, in liquid phase sintering (when a liquid phase is present in powder compact during sintering), the mechanical properties of a material are degraded, Kang, (2005).

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.3 Conclusions

According to ASTM (American Society for Testing and Materials) standards fire bricks for refractory lining are Standard Fireclay bricks with I.S.6 quality with chemical property of 30 % Al_2O_3, 2.00% Fe_2O_3 with MOR of 0.965MPa which can withstand up to 1300^0C.

The average MOR of the wet pressed fired samples of upland ant-hill clay was found to match that recommended by ASTM standards for refractory materials and the percentage of elements found in the upland ant-hill clay for all the samples from the three geographical sites showed a close compliance with ASTM standards for a refractory material. The analysis therefore suggests that the ant-hill clay can be used as a refractory material up to a temperature of 1150^0C.

5.4 Recommendations

From the results of this study, the following recommendations were made;

1. Further studies should be carried out to determine the integrity of upland ant-hill clay temperatures beyond 1150^0C.
2. A study should be carried out to investigate why dry compressed and slip casted upland ant-hill clay cracks and warps after firing.

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APPENDIX 1

PRIMARY DATA

Table A1: Fired slip casted brick samples: - Namagunga

Samples	Thickness(cm)	Width(cm)	Length(cm)	Load(N)
1	3.20	3.28	12.82	8.7
2	3.21	3.28	12.82	4.9
3	3.20	3.27	12.81	6.7
4	3.20	3.28	12.81	4.7
5	3.20	3.28	12.81	8.6
6	3.20	3.28	12.81	6.2
7	3.21	3.28	12.82	8.7
8	3.20	3.27	12.81	7.9

Table A2: Fired slip casted brick samples:-Kyambogo

Samples	Thickness(cm)	Width(cm)	Length(cm)	Load(N)
1 & 4	3.24	3.26	13.08	27.8
2	3.43	3.25	13.10	26.9
3	3.37	3.25	13.08	10.8
4	3.37	3.25	13.08	29.9
5	3.33	3.26	13.08	27.8
6	3.37	3.25	13.08	30.0
7	3.34	3.25	13.10	28.9

Table A3: Fired wet pressed brick samples:-Nkombe

Samples	Thickness(cm)	Width(cm)	Length(cm)	Load(N)
1	1.00	3.95	9.40	300.0
2	1.00	3.95	9.40	355.0
3	1.00	3.95	9.40	495.0
4	1.00	3.95	9.40	386.5
5	1.00	3.95	9.40	367.2
6	1.00	3.95	9.40	395.7
7	1.00	3.95	9.40	338.1
8	1.00	3.95	9.40	390.1

Table A4: Fired wet pressed brick samples:- Namagunga

Samples	Thickness(cm)	Width(cm)	Length(cm)	Load(N)
1	1.00	3.95	9.40	67.0
2	1.00	3.95	9.40	48.9
3	1.00	3.95	9.40	52.1
4	1.00	3.95	9.40	52.9
5	1.00	3.95	9.40	52.5
6	1.00	3.95	9.40	48.4
7	1.00	3.95	9.40	55.6
8	1.00	3.95	9.40	47.8

Table A5: Fired wet pressed brick samples-Kyambogo

Samples	Thickness(cm)	Width(cm)	Length(cm)	Load(N)
1	1.00	3.95	9.40	51.7
2	1.00	3.95	9.40	38.0
3	1.00	3.95	9.40	30.0
4	1.00	3.95	9.40	39.5
5	1.00	3.95	9.40	37.6
6	1.00	3.95	9.40	40.4
7	1.00	3.95	9.40	38.9
8	1.00	3.95	9.40	40.6