

**ASSESSMENT OF ARTISAN CLAY BRICKS ON
PERFORMANCE OF STRUCTURAL STRENGTH,
CHEMICAL STABILITY AND DURABILITY IN
UGANDA**

By

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by Kyambogo University, a research dissertation; titled “Assessment of artisan clay bricks for structural strength, chemical stability and durability;” in fulfillment of the requirements for the award of Master of Science in Construction Technology and Management Degree of Kyambogo University.

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DECLARATION

I, Moses Nabbala Mumpembe, hereby declare that this research is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree of a University or other Institution of Higher learning, except where due acknowledgement has been made in the text and reference list.

Signed:  Date: 23/8/2021

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I thank the Almighty God for granting me the gift of life, mercies and guiding me during the preparation of this research report and ensuring that my dreams are achieved. Great thanks go to my family and friends who always encouraged me morally and financially to ensure that this research was completed. In a special way, I take this opportunity to acknowledge the individual persons that have been helpful in production of this research. Firstly, to my Supervisors, Dr. Lawrence Muhwezi and CEng Dr. Michael Kyakula for their tireless efforts in ensuring this research dissertation is completed. I wish to acknowledge the effort of Professor John mango Magero who honoured my request to test samples in Makerere University Department of Geology. Great thanks go to Eng.Dr. Charles Wana Etyem at Warner Consultants for the encouragement he has accorded me in pursuing this Master programme and senior analyst technician Mr. Kasule Willy at Department of Geology and Petroleum studies in analysing the percentage minerals available in the samples in raw form and in purified state. Salutations goes to my employer Mr. Ide Keich the chief Consultant Yokogawa Architects and Engineers (Japan Tokyo) for allocating me time and allow free use of office internet for my research. Exception thanks go to Mr Ochieng Paul at Kyambogo University Civil Materials' Laboratory for crushing tests of local bricks from Mukono, Lira, improved chemical composition artisan bricks from purified clay of Mukono & Lira, improved moulded bricks from raw clay of Mukono and Lira.

DEDICATION

I dedicate my dissertation work to my family and many friends. A special feeling of gratitude to my course mate (Eng.Mpaata Steven, Eng. Kilenzi and Mr. Isooba John) whose words of encouragement and push for tenacity ring in my ears.

I dedicate this work and give special thanks to my best friend/field mentor Eng. Dr. Wana Etyem for his wonderful providence and encouraging words in finishing this Masters' programme.

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LIST OF ACRONYMS

°c.....	Degrees centigrade
Fig.....	Figure
MR.....	Mister
MPa	Mega pascals
ml.....	Milli litre
rpm.....	Rounds per minute
SEM.....	Scanning electron microscope
Temp.....	Temperature
X-RD.....	X-ray diffraction
X-RF.....	X-ray fluorescence

ABSTRACT

Bricks are oldest building materials since 7000BC, and are preferred as building material due to their high compressive strength, fire & weather resistance, thermal & sound insulation and durability. The artisan clay bricks in Uganda are characterised with low strength, erosion, tiny cracks, lime pop out, warping, efflorescence and high-water absorption. The raw clay and artisan burnt clay brick samples were collected from artisan brick making places (sites) from Eastern, Central and Northern Uganda. The sampling was done using IS-5454 procedures. Testing was carried out for; water absorption, mineral percentage investigation in natural and purified clay in terms of SiO_2 , Al_2O_3 , Fe_2O_3 & CaO , compressive strength of the artisan clay unit, improved chemical composition artisan clay units from purified clay and improved molded bricks from raw clay. Results indicated that mineral requirements for manufacturing bricks was not satisfactory; for artisan bricks, they had very low characteristic strengths of 0.63N/mm^2 for Lira and 0.38N/mm^2 for Mukono samples. Refining and change on molding process was done and the raw clay structure shifted to the positive side of the required mineralogy. Fired bricks on testing gave higher characteristic strengths of 2.2 N/mm^2 after purifying and 3.3N/mm^2 after use of improved mold for Lira, 5.12 and 2.62N/mm^2 respectively for Mukono, slight efflorescence and low water absorption. This study therefore recommend that the artisan do include both clay refining processing and constant force kneaded clay pressing in the manufacturing process.

Key words: Strength, brick structure, chemical stability and durability in Uganda

CHAPTER ONE

INTRODUCTION

1.1 Background

Bricks are the commonly used forms of building materials in the construction of buildings in the world and are one of the oldest known building materials dating back to 7000BC. Bricks were used during the time of Ancient Egyptians, the Romans, and the Mesopotamians and the gothic period when they became very common in the northern Europe. Clay bricks have been widely preferred as building material because of their high compressive strength, durability, fire and weathering resistance, thermal and sound insulation (Frontiers of Architectural research, 2017). The fundamentals of brick manufacturing since ancient times have not changed (Brick industry Association, 2006). Basic principles of manufacturing bricks are fairly the same but individual manufacturers do tailor their manufacturing process to fit their particular clay raw materials. In due course of tailoring the process to fit a particular raw clay material, some manufacturers do make mistakes that can lead to poor quality products. The poor brick products are characterized by lime pops, blistering (tiny holes), cracks, warping, softness or low strength under burning, efflorescence, brick erosion, high rate of water absorption etc.

Bricks in first class when immersed in water, should not absorb more than one sixth of its dry weight, second class should not absorb more than a quarter of its dry weight (Khanna, 2008). For brick manufacturing, clay must possess some specific

properties and characteristics. Clay is one of the most abundant natural materials on earth (Brick industry Association, 2006). Clay do occur in three principal forms i.e., Surface clays, shale's and fire clays of which of these forms have similar chemical compositions (Brick industry Association, 2006). The three forms are composed of silica and alumina with varying amounts of metallic oxides. The type and source of clay used in the manufacturing of bricks varies greatly depending on the geographical locations of the manufacturing site (Chidiac et.al., 2007). The manufacturer minimizes variations in chemical compositions and physical properties by mixing clay from different locations in the pit. During mining it is observed that there is a variation of chemical composition even in the same pit. These variations are compensated for by varying manufacturing processes. Clay bricks in Uganda are manufactured by Artisans, small and medium scale manufacturers. Around 84% of all Ugandan houses have brick walls compared to the 12% which is built with mud and poles (Hashemi et.al., 2015). The artisan clay bricks manufacturers' products are estimated to be over 80% of the brick products in Uganda and are characterized with defects on the market. Artisan clay bricks are relatively cheaper than medium scale manufacturers in Uganda. Clay bricks manufactured by the artisans in Uganda and Tanzania are more than 10% wasted during transportation, handling and construction process on sites (Hashemi et.al., 2015)

To address the issue of artisan clay bricks for structural strength, chemical stability and durability in Uganda, this research focused on the study of the right manufacturing process, identification of the physical and chemical properties of raw clay to be used as per geographical location, design of simple methods of

refining raw clay to meet specific characteristics properties of producing durable, chemically stable and strong burnt clay brick.

1.2 Statement of the problem

The artisan manufactured clay bricks in Uganda are largely characterized by defects like lime pop out, warping, high water absorption, efflorescence/poor appearance of built walls (Figure 1.1) due to chemical imbalance of the clay brick (Federico et.al, 2005), cracks as seen in Figure 1.2, erosion in Figure 1.3, blistering (Mousharraf et.al,2011) because of larger sizes of earth particles & low compressive structural strength due to low temperatures of firing (Karaman et.al., 2006). These eventually lead to low durability of building clay bricks and lack of trust for structural specification during design process, high projects cost due to high waste generation during handling and construction and variations in quality of brick products. This research, therefore, intends to improve the quality of bricks through balancing of chemical constituents of clay and improving on the artisan manufacturing methods for quality sustainability of brick manufacturing artisans in Uganda.



Figure 1.1 : Efflorescence on built walls



Figure 1.2 : Cracks and breakages of burnt clay brick



Figure 1.3 : Erosion of burnt clay brick in built wall

1.3 Objectives of the study

1.3.1 Main objective

The main objective of the study was to assess artisan clay bricks on performance of structural strength, chemical stability and durability in Uganda.

1.3.2 Specific objectives

The specific objectives of the study were:

- i. To determine the chemical percentage content (Al_2O_3 , SiO_2 , Fe_2O_3 & CaO) compositions of clay locally used by the artisans, in manufacturing bricks in Uganda;
- ii. To determine the percentage chemical content (Al_2O_3 , SiO_2 , Fe_2O_3 & CaO) composition ratios as related to the ideal composition for quality ceramic industrial manufacturing.
- iii. To establish a new method of manufacturing improved artisan clay brick to meet specific characteristics properties of producing durable, chemically stable and good structural strength burnt clay brick.
- iv. To establish the present manufacturing process used by the artisans in the manufacture of local clay bricks

1.4 Research questions

The research was aimed at addressing the following research questions:

- i. What are the natural percentage chemical (Al_2O_3 , SiO_2 , Fe_2O_3 and CaO) compositions of artisan brick making clay in specific

geographical locations in Uganda?

- ii. How can the natural composition of the percentage chemical (Al_2O_3 , SiO_2 , Fe_2O_3 and CaO) be improved to produce chemically stable, durable and strong artisan brick?
- iii. What can be done to improve the brick manufacturing process to produce the chemically stable, durable, structural strength and reliable artisan clay brick for construction?
- iv. What methods do artisans follow during manufacturing of local clay bricks in Uganda?

1.5 Justification of the study

Building projects (that employs artisan local clay bricks), incur high costs during handling, transportation and construction because of weak nature of the artisan bricks. This research seeks to mitigate/reduce these costs. Design Consultants need make use of reliable artisan locally manufactured clay brick for design specification. This research seeks to improve manufacturing process for production of reliable artisan clay brick and thus improve structural strength, chemical stability and durability. Dampness due to poor class of bricks that absorption high water in the houses built by the use of low-class artisan brick need to be eliminated. Defects largely characterised with efflorescence turn houses poor looking because of the migrations of the salts, and this research seeks to minimize these effects.

1.6 Significance of the study

The study has provided adequate information to consulting engineers a basis of design specification on the grade of artisan clay brick with improved manufacturing process by Ugandan artisans. The research has provided adequate information regarding the purification of the raw clay to get the appropriate percentage chemical composition leading to chemically stable, durable and structural clay artisan brick that is economical for structural works in Uganda. The introduction of the clay purification formula and improved molding will lead to production of quality artisan clay brick consequently increase time interval for repainting the houses, high compressive crushing strength, smart looking products, add value to knowledge body and hence value engineering.

1.7 Scope and limitations of the study

1.7.1 Content

The research was limited to manufacturing of brick from raw and purified clay, tests for water absorption, compressive strength tests, efflorescence of the improved chemically composition artisan, improved molded brick & artisan burnt clay brick, percentage chemical analysis of (Al_2O_3 , SiO_2 , Fe_2O_3 and CaO) for both raw clay and purified clay.

1.7.2 Geographical

Representative clay samples were obtained from the artisan manufacturing sites in the districts of Mukono, Lira and Kamuli.

1.7.3 Time

The research was conducted in Uganda from December 2018 to October 2020

1.8 Conceptual framework

The structural strength, chemical stability and durability of clay bricks depend on the chemical composition of clay and on the manufacturing process which includes mixing, proportionating of clay constituents in raw clay through refining, drying and firing. The dependent variables which are indicators of quality for classifications of bricks are compressive strength, water absorption and efflorescence. The independent variables are the manufacturing process used by the artisan and the chemical structure of the clay used.

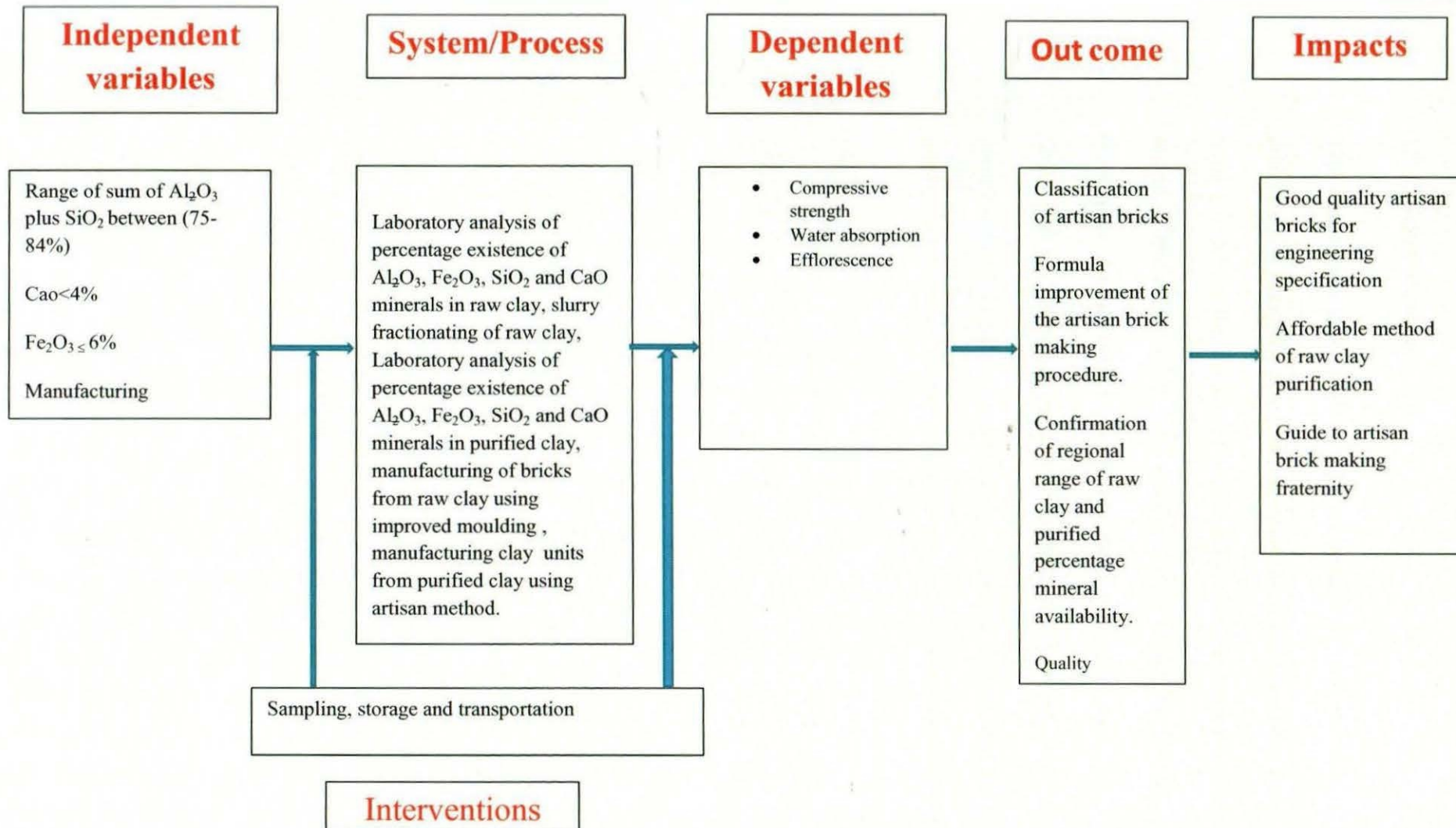


Figure 1.4: Conceptual frame work

1.9 Chapter Summary

This chapter has given a historical back ground of when the brick technology started and why it is preferred as a building material. It has stated the reason as why there is need to address the causes of poor quality for purposes of achieving a structural sound, chemically stable and durable brick made by the artisans in Uganda. Conceptual frame work to guide the study was also presented. The next chapter deals with the literature related with the technology of purifying clay, chemical compliance of ceramic manufacturing, sintering and effects of firing to the clay products to density, compressive strength, water absorption and efflorescence.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents available information of the occurrence and chemical composition of brick making clay, percentage mineral compositions of clay for optimum quality manufacturing of clay brick, particle sizes required of clay for optimum quality, firing of clay bricks, densities of common encountered soils and physical properties of clay bricks on firing, methods of refining clay, and analysis of clay properties and field testing of the clay brick.

2.2 Occurrence and chemical composition of brick making clay

Clay occurs in three principal forms i.e., surface clays, shale and fire clays, all of which have similar chemical compositions but different physical characteristics (Brick Industry Association, 2006). The surface clays may be the up thrusts of older deposits or of more recent sedimentary formations. They are found near the surface of the earth. Shales are the ones that have been subjected to high pressures until they have nearly hardened into slates and fired clays are usually mined at deeper levels than other clays and have refractory quantities (Brick Industry Association, 2006). The type and source of clay used in the production of bricks varies greatly depending on the geographical location of the production site. In a study titled the use of Waste Material in the Manufacture of Clay Brick revealed that the chemical composition of common types of brick making clay and shale was SiO_2 , Al_2O_3 , Fe_2O_3 , TiO_2 , CaO , MgO , Na_2O , K_2O and

LOI (Federico et.al., 2005, A.C. DUNAHAM,1990, Moreno. Tova et.al., 2017). The main difference between clay body types is silicon dioxide (SiO_2), Aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3) and CaO contents (Federico et.al., 2005). Silicon dioxide and the aluminate are major composition of the clay that makes a brick and the rest are regarded as impurities.

In a study titled Mineralogical and Chemical Composition and Distribution of Rare Earth Elements in Clay-Rich Sediments from Central Uganda also revealed that when an opening is made with in the clay zone it exhibits layers ranging from uppermost dark grey layer that is rich in organic matter under which a grey layer exists and then a brown layer, which becomes more brown near the top of the water table and in the same study the clay sediments exhibited the major and minor elements of the clay rock as: SiO_2 , TiO_3 , Al_2O_3 , Fe_2O_3 , MgO , CaO , Na_2O , k_2O , P_2O_3 , Llo (Nyakairu et.al.,2001). In mineralogy of clay, most particle sizes are of dimensions of $2\mu\text{m}$ and less which are responsible for the cohesion and plasticity of moist clay (Dhir, 1996).

2.3 Optimum composition of clay for quality manufacturing of clay bricks

Clay is the principal raw material in the traditional ceramic manufacturing industries. The features that most industries mostly look for in clay are mainly the composition and particle size which determine the feasibility of that clay to be processed (Mousharraf et. al., 2011). Composition and particle size of the clay to be used for brick manufacturing are subject to distinction based on origin of clay. Clays found in the origin is called Residual clays. These clays are typically deposited along the igneous rocks from which they are formed and are obtained in relatively

pure state. These are found to be coarser particles sizes with wide particle sizes distribution and show lower plasticity.

Another type of clay is sedimentary clays that are deposited by transportation from their origin by natural agencies like water, wind etc. The grading action of clay particles in water, wind and ice results in very fine particles sizes giving the sedimentary clay very high plasticity (Mousharraf et.al., 2011). (In a study conducted by the Department of Materials and Metallurgical Engineering, BUET (Bangladesh), revealed that Quartz lowers the plasticity of the green body and leads to micro cracks formation in the fired body (Mousharraf et.al., 2011). It also revealed that white clay has high silicon content and at the same time has substantial amount of aluminate and fairly low impurity content in it and it possesses the greatest potential to be turned into industrial suitable raw materials for the traditional ceramic manufacturing (Mousharraf et.al., 2011). When the raw clay is much higher in silicon dioxide, ferric oxide and Titanium oxide and falling short in aluminate content makes the raw material unsuitable for ceramic manufacturing (Mousharraf et.al., 2011). The strength, durability and absorption of the resulting ceramic products are dependent on the state and nature of sintering within the brick. Sintering is a state reached during firing at a temperature above 1100°C when minerals within the clay melt and fill gaps of other clay particles to increase the strength, density, durability and lowers the absorption of water as shown in the Figure 2.1.

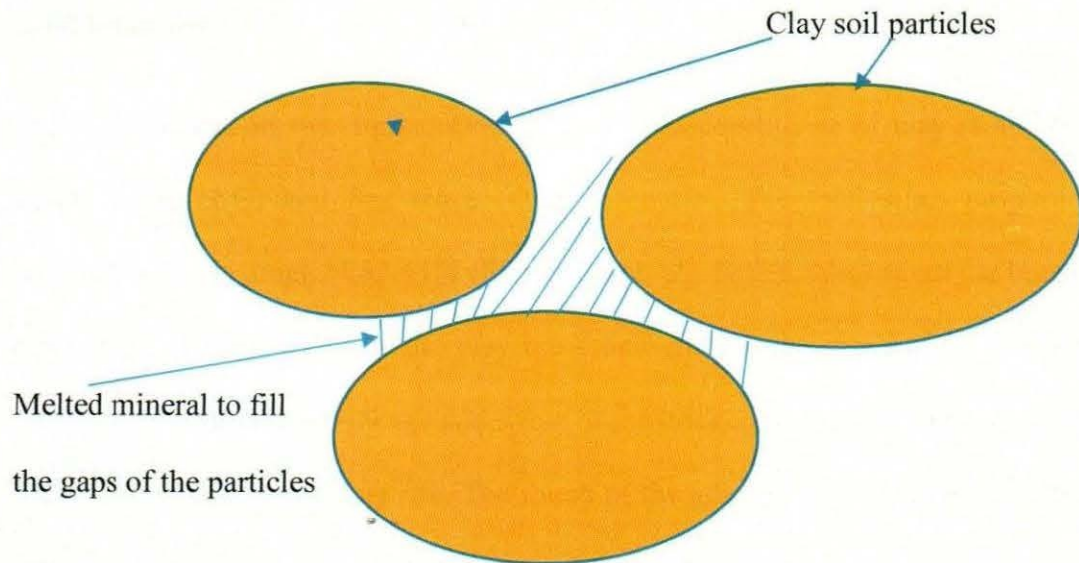


Figure 2.1 : Sintering on firing

For purposes of producing fired clay brick, a silicon dioxide content of between 55-70% is ideal (Chidiac et.al.,2007). The total percentage sum for the silica and aluminate ranges from 75% to 84% (Federico et al, 2005) by weight of the raw clay materials and the rest of the impurities would take up the rest of the portion for quality product.

2.4 Ideal mineral percentage requirement for earth soils for quality brick manufacturing

2.4.1 Alumina (Al_2O_3)

Alumina is required in the range of 22-32% (Fernandes et. al., 2010). All clays are basically hydrous aluminium silicates. Clays are responsible for plastic character of mud. During manufacture of bricks, if alumina is present in higher proportions the brick products do shrink and develop cracks on drying and if they are in smaller proportions brick would not be molded easily and nicely. The use of the range of the percentage (22-32%) proportion is for imparting the bricks with sufficient plasticity (Fernandes et. al., 2010).

2.4.2 Silica (SiO₂)

Silica is present in two forms. One as combined constituent of clay (Kaolinite- $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) and free silica (sand or quartz). The total silica proportion required is in the range of 53-61% (Fernandes et. al., 2010). Silica takes the biggest percentage of the portion of the clay brick and silica is responsible for strength, hardness, resistance to shrinkage and shape of the brick and also to a great extent for the bricks' durability or long life. Too much of the silica in the brick earth making material results in brittleness and porous structure of the brick and may not sinter easily.

2.4.3 Lime (CaO)

The maximum required for brick making is 4% (Chidiac et.al., 2005), this component makes burning and hardening of bricks quicker and is considered desirable with the following conditions: -

- (a) Not more than 4 % because in that case, it may cause excessive softening of bricks on heating (lime and magnesia acts as fluxes)
- (b) Must be present only in finely powdered and thoroughly dispersed form and if present in small grains or nodules the lime itself will get slaked(heated) and once the brick made with this kind of lime is used, lime in it will easily get hydrated and cause disintegration of brick. Magnesia which is easily associated with lime has a similar effect. It is their total percentage which must be considered while determining the composition of the brick earth (Chidiac et. al., 2005).

2.4.4 Iron oxide

Iron oxide (4-6) % (Chidiac et.al., 2005) is required in the brick earth and it also work like oxides of calcium and magnesium as a flux i.e., lowers down the softening temperature of the silica. The iron oxide in addition to work as flux, it imparts the red colour to the brick. Shortage of iron oxide in the earth soil will lead to yellow colour or light red. Yellow colour may also show the incomplete sintering of bricks.

2.5 Firing of clay bricks

2.5.1 Engineering properties of clay bricks on firing

(a) Compressive strength

Compressive strength of brick is remarkably improved by firing at high temperatures as shown in Table 2.1, 2.2 and Figure 2.2 (Karaman et.al., 2006). Increase in the compressive strength is due to the decrease in the porosity and increase in bulky density with increasing temperature. Increase in firing time does no big effect on the compressive strength according to experiment done by Karaman et.al., 2006 when the firing time of from 120 minutes to 148 minutes resulted in small increase of 7% in the compressive strength of clay brick. Increasing firing time does not improve on the quality of brick and result in waste of energy and time (Karaman et.al., 2006).

Table 2.1 : Effect of firing time and temperature on compressive strength of clay bricks

Effect of firing time and temperature on compressive strength of clay bricks					
Firing temp. °C		Compressive strength (Mpa)			
		120	240	360	480
700	Mean	8.532	8.827	9.022	9.12
	Sd	0.211	0.288	0.26	0.22
800	Mean	11.4	11.4	11.7	11.9
	Sd	0.464	0.356	0.35	0.294
900	Mean	15.4	15.5	15.4	16.1
	Sd	0.535	0.2	0.267	0.2
1000	Mean	22.85	22.66	22.94	23.11
	Sd	0.7	0.306	0.366	0.238
1100	Mean	31.3	31.2	31.1	31.4
	Sd	0.048	0.194	0.105	0.294

Source :(Karaman et.al., 2006)

Table 2.2 : Effects of firing temperature on compressive strength of clay brick

Firing temp. °C	Compressive strength N/MM2
0	1
800	10
900	75
1000	24
1100	71
1200	90
1250	82

Source:(Johari et. al., 2010)

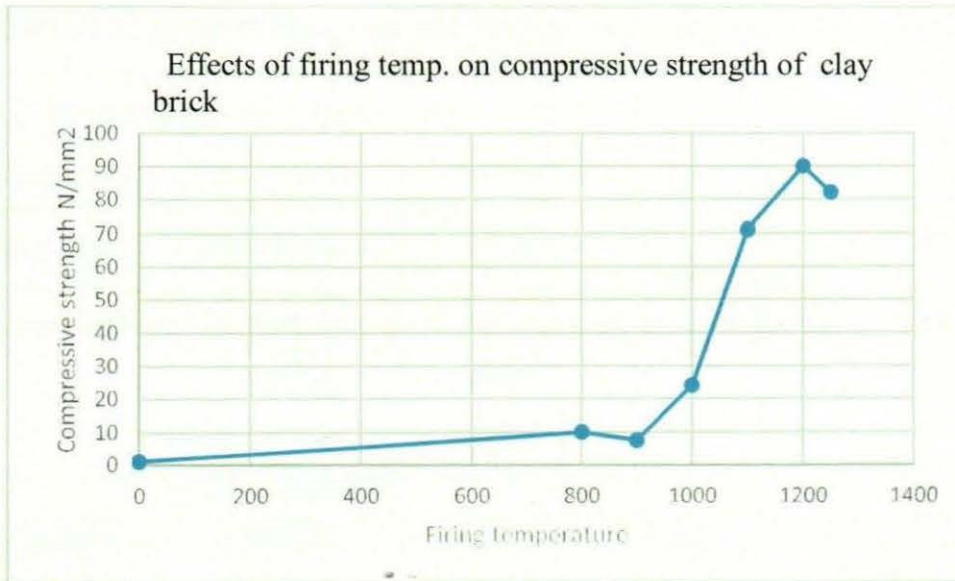


Figure 2.2 : Effects of firing temp. on compressive strength of clay brick

Source :(Johari et.al., 2010)

(b) Density

Density of brick depends on specific gravity of clay, methods of manufacture, and degree of burning (Table 2.3). Density of burnt bricks made with clay usually exceeds 1.6g/cm^3 and is averagely 2.0g/cm^3 . When density of a brick decreases, its strength and heat conductance decrease and water absorption increases. Firing time longevity has no effect on density of clay brick table 2.3 (Karaman et.al., 2006).

Table 2.3 : Effect of firing time and temperature on density of clay bricks)

Effect of firing time and temperature on Density of clay bricks					
Firing temp.0 C		Firing time(min)			
		120	240	360	480
		Density g/cm ³			
700	Mean	1.67	1.68	1.67	1.67
	Standard deviation	0.0469	0.048	0.02	0.0177
800	Mean	1.7	1.69	1.7	1.71
	Standard deviation	0.0245	0.2361	0.3	0.0424
900	Mean	1.74	1.73	1.75	1.77
	Standard deviation	0.0265	0.02	0.0265	0.0283
1000	Mean	1.77	1.77	1.76	1.77
	Standard deviation	0.0469	0.0173	0.0173	0.0548
1100	Mean	1.84	1.84	1.83	1.85
	Standard deviation	0.0283	0.0316	0.03	0.0332

Source :(Karaman et.al., 2006)

(c) Water absorption

Table 2.4 : Effect of firing time and temperature on water absorption of clay bricks

Effect of Firing Time and Temperature on Water Absorption of Clay Bricks					
Firing temp.0 C		Firing time(min)			
		120	240	360	480
		Absorption %			
700	Mean	18.19	18.32	18.301	18.33
	Standard deviation	0.248	0.279	0.193	0.226
800	Mean	18.17	18.12	18.08	17.94
	Standard deviation	0.217	0.324	0.324	0.322
900	Mean	16.79	16.58	16.37	16.12
	Standard deviation	0.325	0.319	0.236	0.336
1000	Mean	13.42	13.45	13.31	13.14
	Standard deviation	0.361	0.394	0.206	0.21
1100	Mean	9.25	9.27	9.14	8.97
	Standard deviation	0.394	0.182	0.211	0.382

Source: (Karaman et.al., 2006)

(d) Bending strength

Table 2.5 : Effect of firing time and temp. on bending of clay brick

Effect of firing time and temperature on bending strength of clay bricks					
Firing temp.0 C		Firing time(min)			
		120	240	360	480
		bending strength (Mpa)			
700	Mean	2.255	2.355	2.455	2.453
	Standard deviation	0.227	0.208	0.154	0.184
800	Mean	2.943	2.747	2.944	3.236
	Standard deviation	0.234	0.185	0.419	0.396
900	Mean	3.023	4.119	3.924	4.218
	Standard deviation	0.234	0.318	0.181	0.374
1000	Mean	6.078	5.883	5.983	6.079
	Standard deviation	0.244	0.258	0.338	0.558
1100	Mean	8.336	8.531	8.63	8.729
	Standard deviation	0.243	0.231	0.207	0.637

Source:(Karaman et. al., 2006)

The brick structure formed at lower temperatures (840-960 °C) remained essentially the same until temperatures of over 1080°C are reached. The porosity of brick shows an increment of 1.4% and 0.1% from 800°C to 900°C and 900°C to 1000°C, respectively (Fig. 2.4).

(e) Porosity

Table 2.6 : Effect of firing temp. on porosity of clay brick

Effect of firing temp. on porosity of clay brick	
Firing temp. 0 C	Compressive strength N/mm2
800	37
900	38
1000	39
1100	27
1200	14
1250	6

Source:(Johari et.al., 2010)

Effects of firing temp. on porosity of clay brick

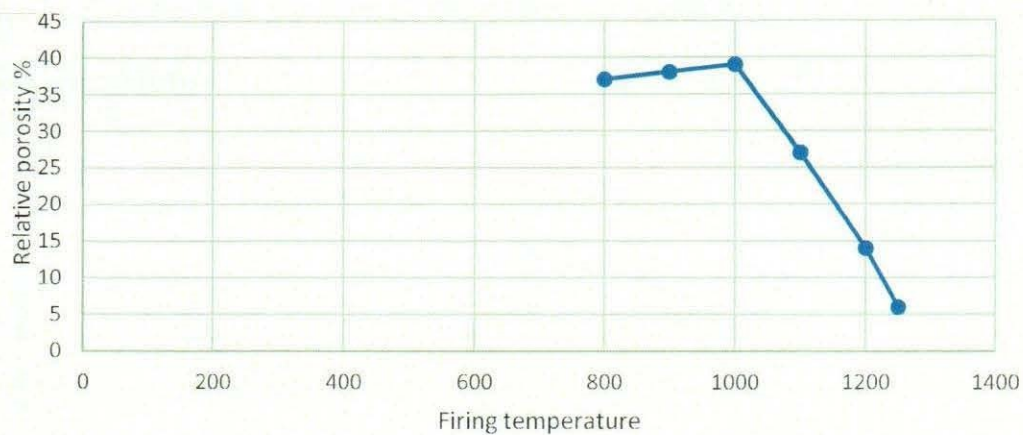


Figure 2.3 : Effect of firing temperature on porosity of clay brick

Source: (Johari et.al., 2010)

The increase in porosity is the result of diffusion at relatively low temperature without significant shrinkage (Johari et.al.,2010) The shrinkage value for temperature 800°C, 900°C and 1000°C is 0.31%, 0.50% and 1.04%, respectively. The surface also looks rough and a bit dusty. The bricks that are sintered until 1000°C are considered as having a porous structure since their water absorption rates are higher than 25%, as shown in Figure 2.3.

(f) Bulky density and water absorption capacity

The bulk density and firing shrinkage of brick increases with the increasing firing temperature while heating the brick from 700 to 1100°C (Shanti,2020). Water absorption capacity of the fired clay bricks decreases with the increase in the firing temperature (Tsega,2017). Water absorption decreases significantly when the temperature increases due to the formation of the amorphous silica at high firing temperatures (Caltron et.al.,2005). The bricks that are sintered below 1000°C are considered as a porous structure as their water absorption rates are higher than 25% (Rani et.al.,2015).

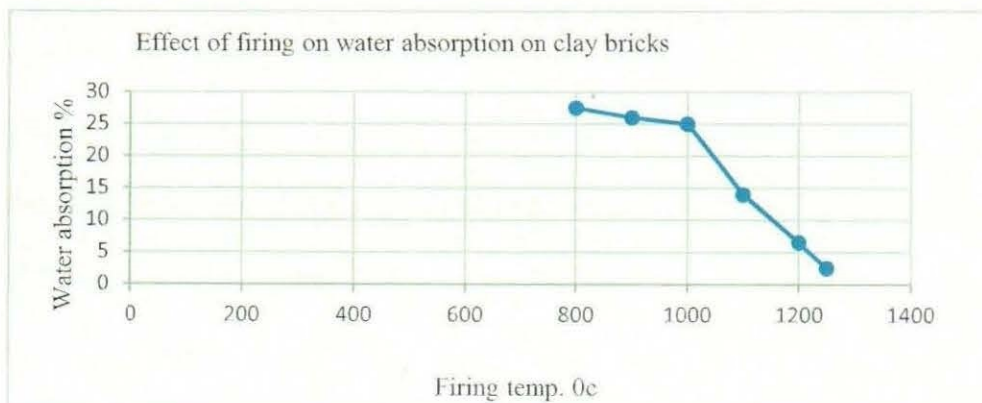


Figure 2.4 : Effects of firing on water absorption on clay brick

Source:(Johari et.al., 2010)

Between 1000°C to 1100°C, the solid-state sintering becomes very significant since the clay body had been fully sintered (Johari et.al., 2020). Very few pores can be seen in the microstructure. Brick porosity value reduces significantly from 39.33% to 27.06% and it was 31% reduction. The purpose of the solid-state sintering process is to develop atomic bonding between particles by a diffusion mechanism (Johari et.al., 2010). This diffusion followed by grain growth will create a dense structure with significant shrinkage. The shrinkage value increases to 74% causing the reduction in volume for brick sintered from temperature 1000°C to 1100°C. A progressive gain in strength can be observed on brick sintered at 1100°C where the compressive strength increased from 25.4N/mm² to 71.8 N/mm². This is also the temperature at which nitrification is first detected by SEM Starting from 1100°C (Johari et.al., 2010), the liquid phase sintering becomes a very important sintering mechanism. During this process, the reduction of pores becomes more significant as the compacted structure starts to increase its performances, such as strength and water permeability. The fired-clay brick sintered at 1100°C begins to diffuse and shrink as the liquid phase starts to form and fill up the pores, creating smaller pores. The brick shrinks 37% when sintered from 1100°C to 1200°C causing the porosity to reduce 47.5%. The effect of firing also causes the water absorption value to reduce 42% lower than the value for brick sintered at 1000°C. The internal surface of pores in bricks sintered at 1200°C and 1250°C has a "glazed" view as seen in Figure 2.5 (Johari et.al., 2010).

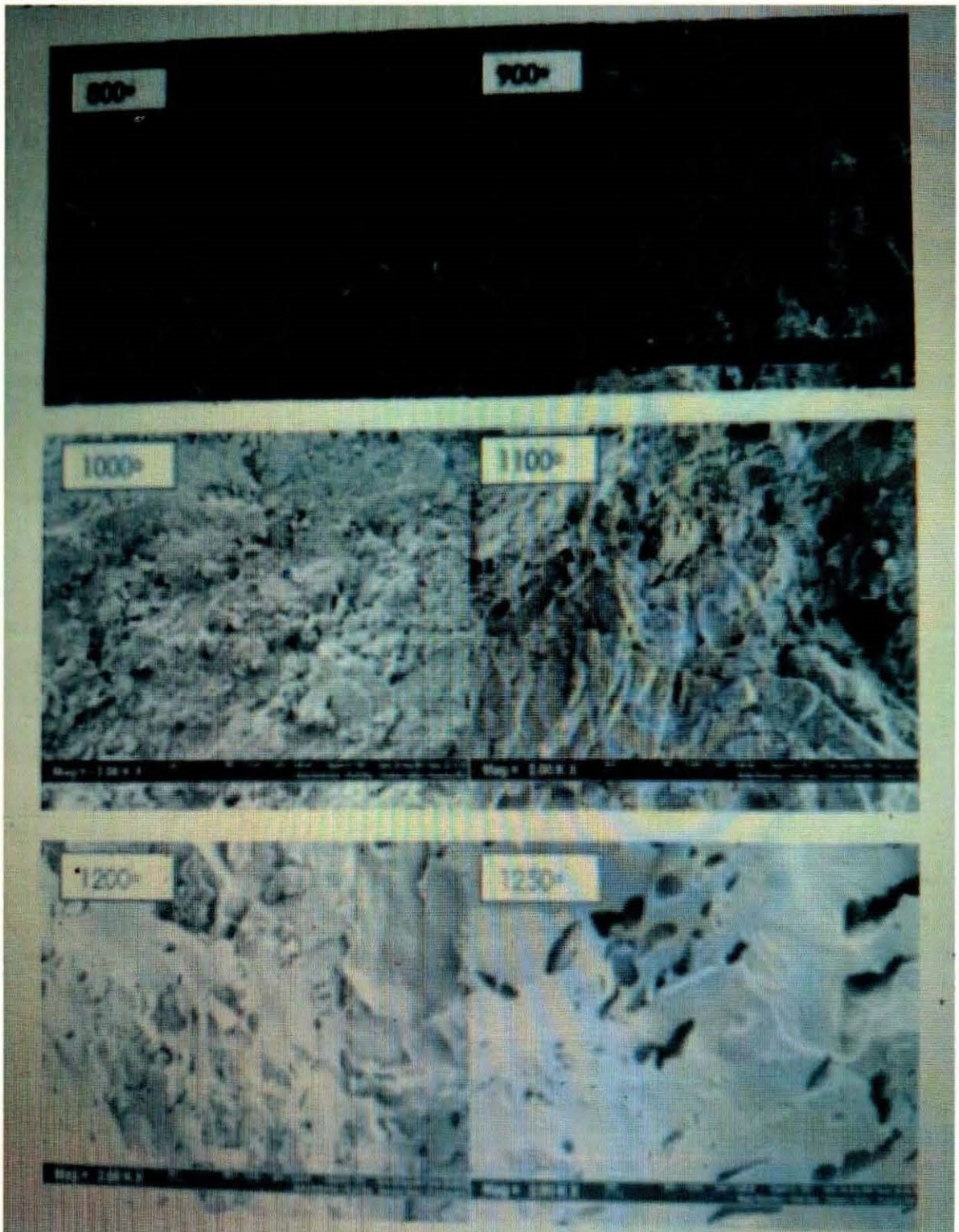


Figure 2.5 : SEM Micrographs for the clay fired at different temperatures

Source :(Johari et.al., 2010)

The sintering process reaches the optimum temperature at 1200°C, whereby its microstructure contains minimum pores with porosity value 14.2 % and produces the highest strength, 89.5 MPa, as shown in Figure 2.2. However, at 1250°C, the microstructure shows larger pore sizes and lower porosity value which is 5.87% with brittle fracture behaviour. The brick becomes more brittle due to a larger portion of glassy phase in the microstructure. Therefore, the strength of the sample becomes lower (83N/mm²). Even though the porosity value is lower than the brick sintered at 1200°C, this only effect on the water absorption properties where the value of water absorption for brick sintered at 1200°C and 1250°C is 6.63% and 2.71%, respectively.

Firing has a positive influence on the microstructure of brick promoting a dense structure with low permeability. At temperatures of 1000°C or above, the technical quality and durability of bricks is generally superior. It displays high in compressive strength, lower porosity and water absorption value. The findings indicate that the physical and mechanical properties of bricks can be controlled to a significant extent by varying the firing temperature. The best firing temperature for fired-clay bricks with good performance of mechanical properties was discovered to be 1200°C (Johari et.al., 2010). There is no doubt about its potential in the construction industry, not only as filler in walling systems, but also as load bearing structures (Johari et.al., 2010). However, due to economic reasons, the firing temperature can be reduced to between 1050°C to 1100°C. The fired-clay brick can still achieve strength around 40-70 N/mm², porosity below 29% and obtain water absorption value below 25%.

2.6 Separation of silica from local clay

Separation of silica from local clay can be separated by various methods i.e., by washing and wet sieving. Silica occurs in three main crystalline forms. The principal occurrence is as the mineral quartz but it also occurs in other rarer mineral forms known as tridymite and cristobalite. It is a very durable mineral resistant to heat and chemical attack and it is these properties that have made it industrially interesting to man. The first industrial uses of crystalline silica were probably related to metallurgical and glass making activities a few thousand years BC. It has continued to support human development throughout history, being a key raw material in the industrial revolution especially in the glass, foundry and ceramics industries. Silica contributes to today's information technology revolution being used in the plastics of computer mouse and providing the raw material for silicon chips (Ara et.al., 2013).

For industrial use, pure deposits of silica sand capable of yielding products of at least 95 percent silica are required. Often much higher purity values are needed. Washing is the most common separation process. Clay may contain quartz, feldspar, mica, coloured minerals, sometimes soluble salts and occasionally organic matter. Washing process is so adjusted to separate clay and silica particles as far as possible. Washing process may, however, need some adjustment depending upon the individual characteristics of the clay under washing. The washing schedule has to be worked out taking into consideration the peculiarity of the clay to be washed and the impurities present. Most sieve analyses are carried out dry. But there are some applications which can only be carried out by wet sieving. This is the case when the sample which has to be analysed is e.g., a suspension which must not be dried; or

when the sample is a very fine powder which tends to agglomerate (mostly $< 45 \mu\text{m}$) – in a dry sieving process this tendency would lead to a clogging of the sieve meshes and this would make a further sieving process impossible. A wet sieving process is set up like a dry process: the sieve stack is clamped onto the sieve shaker and the sample is placed on the top sieve. Above the top sieve a water-spray nozzle is placed which supports the sieving process additionally to the sieving motion. The rinsing is carried out until the liquid which is discharged through the receiver is clear (Ara et. al., 2013)

2.6.1 Separation of silica by washing method

Around 4 grams of sample were mixed with 500 ml water. The mixture was stirred with the help of a stirring machine at a fixed speed (1000 rpm). After stirring, a settling time was given for the mixture. The settling time allowed the silica particles to settle down while the clay particles remained in the suspension. Then the silica and clay particles were separated. The silica particles were dried and after drying weight were measured. During the separation as shown in figure 2.6 of follow of operations, 0.3 grams of an electrolyte [(0.1 gram Na_2CO_3 + 0.2-gram $\text{Na}_2\text{SiO}_3 \cdot 9\text{H}_2\text{O}$) + 100 ml water] was added in the mixture. It aided the separation process (Ara et.al., 2013).

2.6.2 SEM (scanning electron microscope) analysis

Finally, the separated silica particles were taken for SEM analysis. Silica samples were mounted on specimen stub and as silica is not electrically conductive, it was made electrically conductive by gold sputtering.

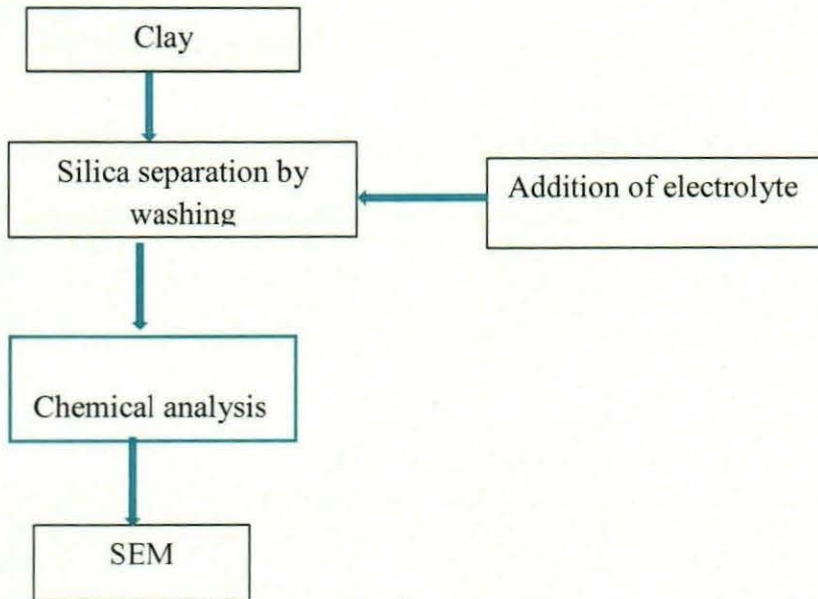


Figure 2.6 : Separation of silica from local clay by washing method

(Ara et.al., 2013)

2.6.3 Separation of silica by wet sieving

At first sample was placed on a sieve having smallest opening, then distilled water was poured on it. Distilled water was used to avoid iron or some other impurities coming into the sample through water. The mixture was allowed to pass through sieve openings. Sand particles remained at the upper portion of the sieve. Washing continued until sand particle become free from clay. Obtained silica was then dried in the oven.

2.6.4 Microscopic analysis

After the separation of clay, silica samples were observed under optical and polarizing light microscope respectively following operation order shown in figure 2.7.

2.6.5 Optical mineralogy

Finally, optical mineralogy was done on the basis of polarizing micrograph. Some mineral other than quartz was identified by this work.

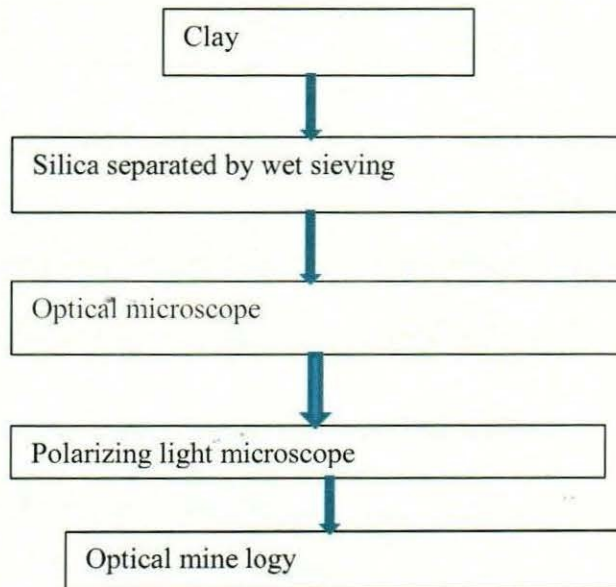


Figure 2.7 : Separation of silica from local clay by wet sieving method

Source :(Ara et.al., 2013)

2.6.6 Result and discussions as per ICMIME,2013

Effect of stirring and settling time Tables 2.6 and 2.7 shows the experimental data of obtained silica during washing method at different parameters. First, the stirring time was varied and the effect was observed. There was no significant change during this operation.

Table 2.7: Data of silica obtained with different stirring time

Data of silica obtained with different stirring time				
Sample (grams)	Water(ml)	Stirring time(seconds)	Stirring speed (rPM)	Silica obtained(grams)
4	500	10	1000	2.13
		15		2.195
		20		2.161
		25		2.093
		60		2.309
		600		2.066

Source:(Ara et. al., 2013)

Then, the settling time was varied to observe the change of silica content. The amount of silica was increased with increasing the settling time.

Table 2.8: Data of silica obtained with different settling time

Data of silica obtained with different stirring time					
Sample (grams)	Water(ml)	Stirring time(seconds)	Stirring speed (rPM)	Settling time(seconds)	silica obtained(grams)
4	500	300	1000	15	2.279
				30	2.251
				45	2.284
				60	2.235
				120	2.465
				180	2.484

Source:(Ara et.al., 2013)

2.6.7 Effect of electrolyte addition

Table 2.9 shows the effect of electrolyte addition on separation process. The effect was significant, as the amount of electrolyte increased the amount of separated silica also increased. Settling time had higher effect than electrolyte in this work.

Table 2.9: Data of silica obtained during electrolyte addition

Data of silica obtained during electrolyte addition					
Electrolyte (ml)	Clay (grams)	Water(ml)	Settling time(seconds)	stirring speed(rpm)	silica obtained(grams)
10	4	500	10	1000	2.153
15					2.172
20					2.216
25					2.218
100 (0.3 g)					2.462
100(0.6 g)					2.481

Source:(Ara et.al., 2013)

2.6.8 Chemical analysis as of ICMIME,2013

Chemical analysis of the separated clay was done to know the percentage of silica. Around 58 percent silica was present in the separated clay. It was clear from the analysis that most of the silica particles retained with clay. Washing method could not separate all the silica particles. So wet sieving was carried out. It gave higher percentage of separated silica than washing method.

2.6.9 Sedimentation/Dispersion

This test is done by shaking a portion of the sample into a jar of water and allowing the material to settle. The material will settle in layers. The gravel and coarse sand will settle almost immediately, the fine sand within about a minute, the silt requiring as much as about an hour, and the clay remaining in suspension indefinitely. The percentage of each component is estimated by comparing the relative thickness of each of the layers in the bottom of the jar, keeping in mind that the larger sized particles will typically settle into a denser mass than the fines (Dang et.al., 2017).

Table 2.10: Visual grain size identification

Visual Grain Size Identification			
Approximate size limit			
Classification	Measured	Sieve	Comparison Example
Boulder and Cobbles	Over 3 in.	>3 in	Grape fruit size
Gravel, Coarse	(3-1) in	(3-1) in	Lemon size
Medium	(1-3/8) in	(1-3/8) in	diameter of a penny
Fine	(3/8in-2mm)	(3/8in-2mm)	pencil diameter of a pea or rock salt
Sand -coarse	(2-0.42) mm	No. 10 - No. 40	Broom Straw diameter to sugar or table salt
Fine	0.42 mm - 0.075 mm	No. 40 - No. 200	Human hair diameter to powdered sugar
Silt	0.075 mm - 0.002 mm	< No. 200	Cannot be discerned with the naked eye
Clay	< 0.002 mm		Cannot be discerned with the naked eye

Source :(Dang et.al., 2017)

2.7 Analysis of clay properties

A number of researches have been carried out so far on clays from various region across the country in order to identify the compositional variation. Such analysis is usually performed with the X-Ray Fluorescence (XRF) and X-Ray Diffraction (XRD) methods. Table 2.11 lists the XRF analysis of some locally available clay types.

In reference to the data in Table 2.11, a comparison of local clay to imported material (standard compositions) would make obvious that the indigenous material is much higher in SiO₂, Fe₂O₃ and TiO₂ content and falling short in Al₂O₃ content. Typically, majority of Silica stay in free form as Quartz. Rest of the

Silica content are associated with Alumina in bonded form, which forms phases like Kaolinite, Halloysite etc (Table2.13). Moreover, amount of impurities like Fe_2O_3 and TiO_2 are also high in most of the local clay types

Table 2.11: XRF analysis of local and imported clay

Composition	Locally Available Clay			Standard Composition	
	Binjiypur clay	Red clay	Black Clay	Ball clay	China Clay
SiO_2	70.08	62.80	53.13	44.63	50.18
Al_2O_3	27.24	20.43	23.41	36.93	33.34
Fe_2O_3	1.03	6.07	4.97	.96	1.88
TiO_2	1.64	.98	.98	3.57	.08
Others	0.0	10.71	18.50	13.91	14.59

Source :(Adnan et.al., 2011)

Although Bijoypur Clay (White Clay) has high SiO_2 content, but at the same time it has substantial amount of Al_2O_3 and fairly low impurity content in it. Hence this clay possesses the greatest potential to be turned into industrially suitable raw material for traditional-ceramic manufacturing.

Table 2.12 shows another XRF analysis, where the compositions of various locally available clay are compared. The data show that % Silica of the local clay are in the range of 65-73 %, Alumina in 22-27, % Iron (III) Oxide in 1-9 and % Titanium Oxide within 1%, which present the challenges of dealing with local clay for the suitability of industrial application due to high Silica content.

Table 2.12: XRF analysis of various locally available clays

% composition	Binjoy pur Clay	Mymensingh Black clay	Mymensingh White clay	Mymensingh White yellowish clay	Mymensingh Yellowish grey clay
Sio ₂	70.08	70.36	73.10	71.34	65.15
Al ₂ O ₂	27.24	24.39	22.10	24.63	23.49
Fe ₂ O ₃	1.03	1.40	1.75	1.57	9.3
TiO ₂	1.65	1.44	1.11	1.44	1.28
Others	0.0	2.41	1.94	1.02	.78

Source :(Adnan et.al., 2011)

Table 2.13 shows the compositional analysis done by XRD of some locally available clay which strongly indicates the presence of Quartz, in all of them. In general, the presence of excess amount of Quartz lowers the plasticity of the green body and also leads to micro crack formation in the fired body. Moreover, long exposure to silica dust causes significant health hazard.

Table 2.13: Summary of XRD analysis of local clays

Local clay samples	Possible phases present
Bijoypur	Kaolinite, Halloysite and Quartz
Mymensingh black clay	Kaolinite, quartz and Biotite
Mymensingh white clay	Kaolinite, Halloysite, Quartz
Mymensingh white yellowish	Kaolinite, and quartz
Mymensingh yellowish gray	Kaolinite, palygoskite and quartz

Source :(Adnan et.al., 2011)

In the analysis of the local clays in china, shows the X-Ray diffraction pattern for three types of clay i.e a pattern for standard China Clay and the existence of Quartz and Kaolinite in the composition, pattern for locally available Mymensingh White Clay and Bijoypur Clay respectively. The XRD patterns indicate the presence of higher amount of Quartz or free Silica and relatively lower Kaolinite (bonded Silica) content in locally available clay in comparison to those in China Clay. Hence, substantial refining action is necessary to make the indigenous material suitable for industrial manufacturing.

Another important factor for clay to be used as raw material is the particle size. Particle size has a significant role on the plasticity of clay. Generally, the smaller the particle size the better is the plasticity of clay. However, there is a lower limit of particle size below which the property starts to deteriorate. China Clay due to its large particle size shows poor plasticity. Thus, plasticity of green clay body is usually improved by adding other clay like Ball Clay which has very fine particle size. Ideally, the average particle size required for green body mixture is around 45 microns.

In case, the mixture has particle size below that, then the green body fails to hold its shape. Table 2.14 shows the particle size distribution of local clay which indicates that local clay has larger particle size. Bijoypur Clay, Mymensingh White Clay and Yellowish Gray Clay have particle size larger than 100 microns, whereas Mymensingh Yellowish Gray and Black Clay have particle size just below 100 microns. In general, local clays have larger particle size.

Table 2.14: Particle sizes distribution and analysis of % residue through sever analyser

Sample	Mesh size		
	+140 mesh	+200 mesh	+325 mesh
Bijoypur clay	38.65	5.72	4.82
Mymensingh white clay	56.47	2.57	8.32
Mymensingh white yellowish clay	16.38	6.61	13.81
Mymensingh black clay	17	5.62	9.1
Mymensingh yellowish	39.05	6.66	8.13

Source :(Adnan et.al., 2011)

Atterberg limits of clays when plotted as a plasticity chart i.e. Plasticity index against plastic limit, aids in identification of clay types and physical properties of clay as shown in figure 2.8 (Bain, 1971). Plasticity index equals to difference between the liquid limit and that of plasticity limit.

The plasticity index gives an indication of the 'degree' of plasticity shown by a clay body and May often be correlated with properties such as specific surface area, dry strength, and rheological behaviour. The plastic limit gives an estimate of the sorptive properties of clays (in this case for water) and may be correlated with other characteristics such as shrinkage on drying (Bain, 1971).

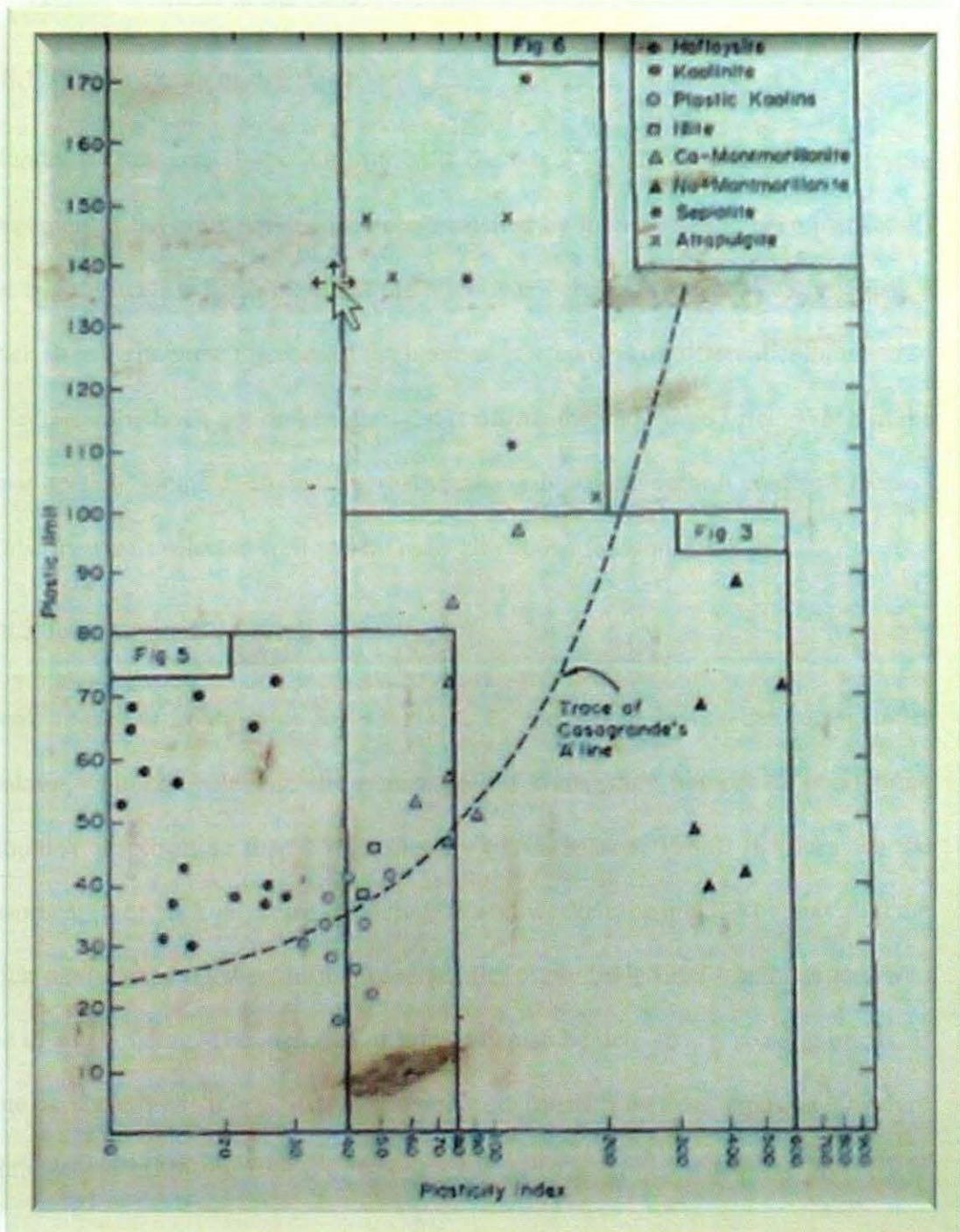


Figure 2.8 : Clay identification

(Brain, 1971)

2.8 Testing of bricks in the field

2.8.1 Test for being under fired:

Handle a brick, see if it's soft., pick off the edges, scratch the surface with your fingernail. If the brick is felt soft, been scratched by finger nail and been placket off the edges then it is confirmed that the brick is under fired (Mason, 1988). Break a brick in half and view the core of the internal. If a 'core' is of different color material is seen and the brick got broken easily, it confirms the underfired brick. When in the cross section, lumps or stones, internal cracks or holes are seen, it confirms the soil probably wasn't selected well and mixed well enough (Mason, 1988).

2.8.2 Test for grade of brick

Soak bricks in cold water for 48 hours. If you weigh bricks before and after soaking, you can calculate the percentage of water they absorb. A good brick shouldn't absorb more than 15% of its dry mass (Mason, 1988). If bricks are too absorbent, they suck moisture out of mortar and weaken the bond. You may find the brick dissolves altogether. In this case, it's definitely underfired - and dangerous to use in any building. The presence of lime may also be detected by soaking bricks. If lime is present as lumps, it may expand and cause fractures, exposing powdery white deposits (Mason, 1988).

2.9 Chapter Summary

This chapter has given brief literature on the existence, occurrence and formation of clay. It has highlighted the types of clay in nature and given the chemical compounds present in raw clay and the ideal percentage of the chemical compounds

required of the earth soils to manufacture a stable, strong and durable burnt clay brick. It has also highlighted the benefits of firing of clay bricks as gain in high atomic bondage that leads to high compressive strength, high density, low water absorption, low efflorescence effect. It has given the methods of refining clay to improve on the structure of the raw clay chemically. The next chapter is methodology that was adopted to achieve the objectives of the study.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter provides the methodology that was adopted in order to achieve the objectives. It describes the conditions of clay in its natural state, process of purifying the natural clay to yield the level of mineral percentage proportionality required for high quality production of clay brick, process of artisan manufacturing of bricks. It further describes the methods of determining the compressive strengths, water absorption, efflorescence ability and classification of bricks.

3.2 Study area

Districts in Uganda were divided into four major regions i.e., northern, eastern, western and central. Districts in each region was randomly sampled. In this line Mukono, Lira, Kamuli and Kisoro were picked from central, northern, eastern and western respectively. However, Kisoro was later eliminated because it was found to be using stones for construction while the bricks in the area are imported from other places and yet funds had been spent in traversing the place in search for artisan brick making sites.

3.3 Sampling techniques, size and instruments

The choice of burnt clay brick making area depended on getting a brick maker who also had a heap of clay from which he had used partly to make the already burnt clay brick. Such places were identified in Mukono and Lira. Unfortunately, there was no brick maker who had clay unutilized and bricks in Kamuli. Therefore, there was no

basis of comparison. However, clay was picked from Kamuli for percentage chemical analysis of aluminium oxide (Al_2O_3), silicon dioxide (SiO_2), iron three oxide (Fe_2O_3) and calcium oxide (CaO) for raw clay.

Samples of burnt clay bricks from each selected brick artisan making areas were obtained following procedures provided in **IS- 5454** which states that for lot of 2002 to 10,000 bricks sample size for compressive strength, breaking load, transverse strength, bulk density, water absorption and efflorescence tests is taken as 5 pieces for each test required. However, 50 bricks were picked from each site to cater for possible damages in transit, handling and any eventualities. The burnt artisan local clay bricks were handpicked from artisan brick making places of Mukono and Lira. The clay samples from Mukono, Lira and Kamuli were loaded in sacks for easy transportation. The samples of natural clay and that of burnt clay bricks were durably and clearly labelled and delivered for storage. At storage, the natural wet clay was given two months to dry. After drying, lamed clay was broken into smaller particles and got packed in plastic bottles and delivered to Geology Laboratory of the Department of Geology and Petroleum studies of Makerere University for testing. Artisan clay bricks were packed and delivered to Materials Laboratory of Kyambogo University for testing. Water absorption and efflorescence test were carried out on the bricks. Questioners were designed to take care of the methods used by the artisans in their manufacturing processes of clay bricks in Uganda.

3.4 Testing procedure

Testing commenced with mineral content analysis of the natural clay from the areas of Mukono, Lira and Kamuli to confirm the percentage natural mineral existence of Al_2O_3 , Fe_2O_3 , SiO_2 and CaO . The natural clay was there after purified using slurry fractionating method taking advantage of different densities of the natural clay constituents in the slurry. After clay purification, the purified clay was analysed on the effect that had occurred on its mineral content rearrangement in the clay structure. Clay units were made from the purified clay using artisan method of moulding and bricks made from raw clay using relative uniform force mould, dried, baked and tested of compressive crushing strength, water absorption and efflorescence. The artisan bricks were also tested for compressive crushing strength, water absorption and efflorescence. Testing was done at Makerere University Department of Geology and Petroleum Studies Laboratory Uganda, Kyambogo University Civil Engineering Material Laboratory Uganda.

3.5 Data presentation

Test results were presented on Standard Test Forms and summarised accordingly as shown in Appendix 1 to give a quicker overview in interpreting results. Further presentations were made in form of figures with representative graphs showing the overall behaviour of the materials.

3.6 Data analysis

The test results obtained were analysed using Microsoft excel. Table of results were generated and bar charts were formed for easy of understanding of the subject matter.

3.7 Research approach and design

This research was experimental since different types of clay and baked clay brick samples from different regions of Uganda were taken for laboratory testing to: -

- (i) Confirm and analyse percentage of natural mineral existence of Al_2O_3 , Fe_2O_3 , SiO_2 and CaO and effect of purifying clay on the percentage existence of Al_2O_3 , Fe_2O_3 , SiO_2 and CaO .
- (ii) Determine compressive strength, absorption and efflorescence effects of the artisan bricks and new manufactured building clay units from purified clay to obtain the relationship between the artisan method of manufacturing, and the manufacturing method that involved clay purification.
- (iii) Determine the purity level /response of clay from different regions of Uganda.

3.8 Analysis for natural and purified clay of the percentage content of Al_2O_3 , Fe_2O_3 SiO_2 and CaO

Samples were tested for percentage content of Al_2O_3 , Fe_2O_3 SiO_2 and CaO in its natural and purified state to determine its conformity to the percentage required to produce the required product for engineering standards that make the brick stable, durable and strong.

3.8.1 Objective of analysis for the natural and purified clay of the percentage content of Al_2O_3 , Fe_2O_3 SiO_2 and CaO

Aluminate (Al_2O_3), silicate (SiO_2), iron three oxide (Fe_2O_3) and lime (CaO) are the major constituents of the earth for brick making (Federico et.al., 2005, Musharraf et.

al., 2011). These constituents must be in certain proportions for quality brick making (Fernandes et.al., 2010). The major objective of the test was to measure the proportions of the constituents of clay, both in natural and purified state and compare with the required chemical clay composition for manufacturing of industrial ceramics that results in high strength, stability and durability.

3.8.2 Significance of analysis for the natural and purified clay of the percentage content of Al_2O_3 , Fe_2O_3 SiO_2 and CaO

The importance of carrying out the analysis for natural and purified clay of the percentage content of Al_2O_3 , Fe_2O_3 SiO_2 and CaO was to know if the constituents of the clay in the regions selected were complying with the right proportions of the earth that produce the brick that is strong, stable and durable.

3.8.3 Apparatus;

The apparatus used included;

- Grinding machine
- Digester
- Automatic absorption spectrophotometer (Agilent 240FS AA)



Figure 3.1: Automatic absorption Spectrophotometer (Agilent 240FS AA)

Source: (Geology laboratory Makerere University)



Figure 3. 2: Aqua Regia (Mixture of Hydrochloric acid and Nitric acid)

Source: (Geology Laboratory Makerere)

3.8.4 Procedure (140/240/280 series AA User's guide)

- i. The clay sample was put in grinding machine and grounded to the powder form.
- ii. The clay powder was then mixed with aqua regia (mixture of hydrochloric acid and nitric acid) for digest.
- iii. The resultant solution/digest was then fixed to the chambers of the absorption spectrophotometer (Agilent 240FS AA) for analysis.

3.8.5 Observations

Readings were recorded in standard form and results were expressed in parts per million (ppm) for both natural state and purified state and percentage were obtained as presented in appendix.

3.9 Clay purification

The clay purification (Adnan et.al., 2011) was to remove the free sand, coarse particles, organic materials and silt from natural clay and remain with bonded silicon dioxide and have significant increase in the aluminate in the composition of the clay samples after sand, coarse particles, organic matter and silt separated from the clay structure.

3.9.1 Significance for clay purification

The significance of the purification process was to confirm the clay structure that is good enough for manufacturing engineering products and separate the impurities of clay from pure clay.

3.9.2 Test apparatus;

The apparatus used included;

- Transparent 20 litre bucket
- Closely weaved cloth
- Stop Watch with accuracy of 0.1s and
- Mingling pad (stick)

3.9.3 Test procedure

- i. Three transparent buckets labelled A, B and C were used in each test.
- ii. In bucket B and C natural sample of the same type of clay was placed to approximately occupy 25% of each transparent bucket by volume.

- iii. Water was then topped on the natural clay to approximately filling to 90% of each bucket by volume.
- iv. The mingling pad was used to stir the clay to mix with water to make uniform clay slurry. Mingling took approximately 30 minutes for brown clay and light grey clay. For dark grey clay it took less than 30 minutes.
- v. A third transparent bucket A in each experiment was covered on top with a closely weaved cloth and secured firm with rubber band.
- vi. The clay slurry in bucket B was poured on top of the secured firm closely weaved cloth on top of Bucket A and the clay trapped on top of the cloth and left to settle and water drip through for 72 hours (3 days).
- vii. The slurry in bucket C was left to settle for 72 hours (3 days) to ensure that the clay structure separates from coarse particles, sand, organic materials and silt. The water on top was siphoned/ sucked off using a clear horse pipe. Data was recorded in a standard form for analysis.



Figure 3.3 Slurry fractionation

Source: (Photo during fractionation exercise)

3.9.4 Observations

- i. The clay that was in bucket C, was left settling and observed to have developed into layers.
- ii. The top most layer was clear water with floating organic materials
- iii. The second layer from top was smooth on touching and sticky
- iv. The third layer from top was smooth but not sticky on touching
- v. The fourth layer from the top was coarse on touching and rough.
- vi. The smooth and sticky layer was scooped using hands from bucket C after siphoning/sucking off the clear water and is from which new building units were manufactured and referred as modified units.
- vii. The clay that was poured on top of the closely weaved cloth on bucket A was seen to allow slow dripping of water through the cloth and after three days a suspension was seen as a filtrate and at processes of pouring the slurry on the cloth, when the coarse materials started appearing onto the cloth, the pouring stopped because the coarse materials are not found to be good.
- viii. The methods used for bucket B and that of C, bucket C method was found to be more perfect because it ensures total separation compared to pouring which can lead to mix silt and sticky clay in the process of pouring since the silt is close to sticky clay in the slurry settling fractioning.
- ix. The yield of the sticky layer was seen more in brown clay, seconded by light grey clay and was list in dark grey clay.

3.10 Compressive strength test

3.10.1 Objective of the test

Compressive strength test is a mechanical test measuring the maximum amount of compressive load a material can bear before fracturing. The major objective of the test was to measure the maximum amount of load that the materials can carry/bear before fracturing i.e., the artisan brick, made brick from raw clay, modified brick from purified clay and compare their results of bearing capacity/characteristics strengths to see if the purification of the clay increases value in terms of strength, stability and durability.

3.10.2 Significance of the test

The test was important in determining the level at which the purification of clay and improved molding affects the bearing strength of the products manufactured from purified clay using artisan molding methods and raw clay using improved moulding as compared to artisan brick.

3.10.3 Sample preparation

The artisan clay brick samples were obtained from parent source and were ready for testing. The clay units from purified clay were molded using artisan molding style; bricks from raw clay molded using improved molding, dried, and baked before tested.



Figure 3.4: Improved metal mold due to its cover weight(10kg) that is used for uniform pressing of tempered clay during manufacturing

Source: (Locally welded to impart cover weight for uniform pressing)

3.10.4 Apparatus;

The apparatus used included;

- Hydraulic compressive testing machine
- Steel measuring tape
- Calculator
- Note book
- Pen



Figure3.5: Hydraulic compressive testing machine



Figure 3.4: Improved metal mold due to its cover weight(10kg) that is used for uniform pressing of tempered clay during manufacturing

Source: (Locally welded to impart cover weight for uniform pressing)

3.10.4 Apparatus;

The apparatus used included;

- Hydraulic compressive testing machine
- Steel measuring tape
- Calculator
- Note book
- Pen



Figure3.5: Hydraulic compressive testing machine

3.10.5 Procedure

- i. All the prepared material was assembled in the laboratory.
- ii. The dimensions of each brick in contact with the bearing surface were taken for each brick.
- iii. The bricks were placed on the bearing plate of the compression testing machine one at a time then the upper plate was lowered by the screw until it touched the brick. All the nobs that allow hydraulic force to be generated were closed and the pumping of the machine was then done to exert force on the brick which was placed between the bearing plate and the upper screwed plate. As the pumping continued a force in kilo newtons was registered on face plate. The force stopped being generated automatically when the fracture occurred in the brick and a reading was taken.
- iv. All contact surfaces and crushing forces for each brick were recorded in a standard form to allow calculation of crushing force for each brick.
- v. Average crushing force for each type from different regions, manufactured bricks from purified & raw clay and artisan was got for comparison.

3.10.6 Reporting

Contact surfaces of each brick to the bearing plates were recorded with corresponding forces readings that caused a fracture.

3.11 Absorption tests

3.11.1 Objective of test

To determine the classification of the bricks (quality) produced by the artisans and improved chemical composition from purified clay and the effects of the extent to the bricks undergo during wet conditions durability and weathering.

3.11.2 Significance of test

- To determine the durability of the artisan improved chemical composition to the standard brick.
- To classify the quality of the artisan, improved chemical composition to the standard brick.
- To show the input of purifying the raw clay.

3.11.3 Apparatus:

The apparatus included;

- Electronic compact scale to accuracy of 0.01 gram
- Transparent water container
- Alarm clock
- Note book
- Pen

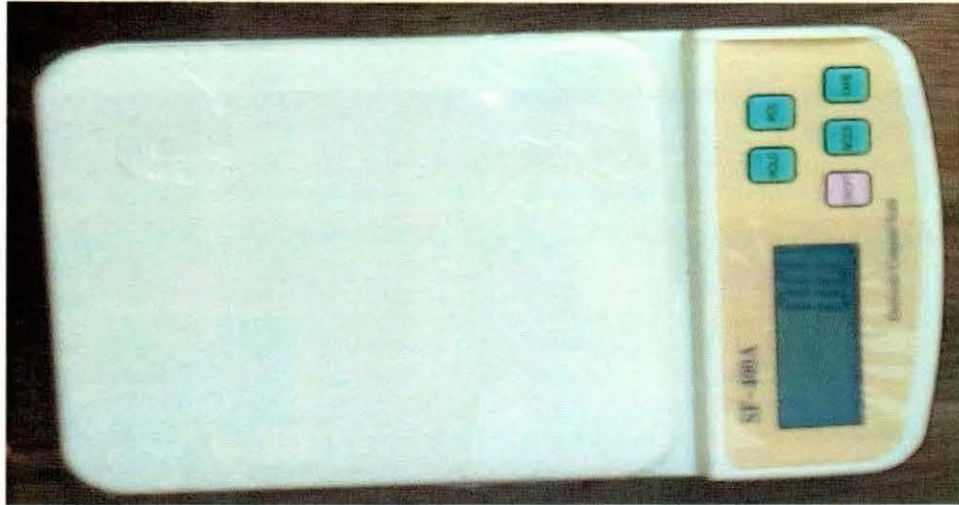


Figure 3.6: Electronic compact scale to accuracy of 0.01gram

Source: (Photo during research activities)

3.11.4 Procedure

- i. Five bricks from artisan sites, five improved molded bricks and improved chemical composition clay units were selected from Mukono and Lira.
- ii. Each dry baked brick was cleaned of loose sand /clay and were marked 1,2,3,4 and 5.
- iii. Each cleaned dry brick was weighed and the dry weight recorded as M1.
- iv. After recording the dry weight, all bricks were immersed in clean water for 24 hours After 24 hours of immersion all the bricks were wiped of water and immediately weighed and recorded M2.
- v. Average weight for the dry and that of the wet were calculated.
- vi. From the averages the dry values and the wet values of the bricks, absorption was calculated as:

$$\text{Absorption} = \frac{(M_2 - M_1)}{M_1} \times 100 \dots\dots\dots \text{Equation 3.1}$$



Figure 3.7: Dry brick being weighed

Source: (Photo during research activities)

3.11.5 Reporting of results

The absorption of the bricks was recorded that lead to the classification of the bricks.

3.12 Efflorescence

3.12.1 Objective

Efflorescence is the migration of salt in a solution form from inner part to the surface of porous material, where it forms a coating. The major objective was to

determine the presence of the alkalis in the bricks and the earth material that was used to manufacture the brick.

3.12.2 Significance

The test provided the knowledge of the detection of the alkalis that are dangerous to the building units as they affect the walls and construction at large. This test was important as it measures the resistance of the building materials' ability to absorb water that would bring dampness in the house and make the plastering of the walls peel off.

3.12.3 Apparatus:

- Transparent buckets
- Alarm clock

3.12.4 Procedure

- i. Five bricks were selected from each sample and the bricks were labelled bearing the name of their origin.
- ii. All the bricks were totally immersed in clean water for 24 hours as shown in figure 3.8
- iii. After 24 hours all were removed and placed under shade where there was enough air circulation.
- iv. After two weeks, the brick surfaces were observed to monitor salt migration that had occurred on their surfaces.



Figure 3.8: Total immersion of bricks in water

Source: (Photo during research operations)

3.12.5 Reporting

Appearances of salts on the surface of the on the brick surface were reported.

3.13 Interviews to the brick making artisans

Forms were designed for purposes of interviewing brick making artisans. Ten artisan brick making sites from each study area of Mukono, Kamuli and Lira were visited and interviewed the artisan, on how they do process their brick making from clay for construction.

3.13.1 Objective of the interviews

Brick making is the process under which a brick is manufactured from the parent material to a sound, durable and strong building unit.

3.13.2 Reporting

The order of brick processing was noted for each individual artisan in different three-study areas

3.13.3 Data presentation

Interview results were arranged in order of response and compared for similarity.

Table 3.1 interview form for brick making artisans in Uganda

Interview form for artisan brick making in Uganda		
Date		Number of years in the field
Place of operation		
Artisan Name		
Code of operation		Individual artisan operation order
A.	Clay mining	
B	Brick molding	
C.	Clay tempering	
D.	Clay identification	
E	Brick seasoning	
F	Brick cooling	
G	Brick burning	
Description of each code per artisan		

Questions were designed for interviewing the artisans as given in appendix

3.14 Chapter summary

This chapter has given a brief methodology adopted to achieve the objective of the study. Described scope of work, testing procedures of the mine logy of clay in raw and purified states, methods of refining clay, testing for compressive strength, water absorption & efflorescence and manufacturing process of the artisan man in Uganda. Interviews made on the artisans on the process of manufacturing clay bricks in Uganda. The next chapter is presentation analysis and discussion of test results

CHAPTER FOUR

PRESENTATION, ANALYSIS AND DISCUSSION OF TEST RESULTS

4.1 Introduction

In this Chapter, the test results obtained through the testing processes are presented in Tables and Figures. Test results analysis was carried out to give the relationship between the findings and the standard construction/material requirements. Explanations have been deduced to give a qualitative understanding between the findings and standard requirements, their impact on the process of purifying natural clay and thus leading to conclusions and recommendations.

4.2 Analysis of natural clay for the percentage content of Al_2O_3 , Fe_2O_3 , SiO_2 and CaO

Table 4.1 presents the results from analysis of natural clay for the percentage content of Al_2O_3 , Fe_2O_3 , SiO_2 and CaO . The aim was to confirm the natural availability of the required constituents for the manufacture of quality bricks in the earth soils.

Table 4. 1 : Results of percentage content of Al_2O_3 , Fe_2O_3 , SiO_2 and CaO in natural state

Sample name	Al_2O_3	Fe_2O_3	CaO	SiO_2
	%	%	%	%
Lira Brown Clay	1.7	1.5	1.3	90.0
Lira Light Grey Clay	2.2	1.1	0.6	85.0
Lira Dark Grey Clay	0.3	0.5	0.09	92.5
Mukono Brown Clay	0.9	1.8	0.2	91.2
Mukono Light Grey Clay	1.1	1.6	0.5	86.1
Mukono Dark Grey Clay	0.7	0.6	1.9	88.8
Kamuli Brown Clay	1.2	0.9	0.7	88.2
Kamuli Light Grey Clay	0.8	0.3	0.9	68.4
Kamuli Dark Grey Clay	0.6	0.4	0.1	98.7

Table 4. 2 : Percentage sum of Aluminate and Silicon dioxide in natural sample

Sample name	Al_2O_3 (%)	SiO_2 (%)	Percentage sum of aluminate & silicon dioxide	Acceptable range (75-84%) (Federico et.al., 2005, Fernandes et.al., 2010)	Remarks
Lira Brown Clay	1.7	90.0	91.7%	84%	Above Max.
Lira Light Grey Clay	2.2	85.0	87.2%	84%	Above Max.
Lira Dark Grey Clay	0.3	92.5	92.8%	84%	Above Max.
Mukono Brown Clay	0.9	91.2	92.1%	84%	Above Max.
Mukono light grey Clay	1.1	86.1	87.2%	84%	Above Max.
Mukono dark grey Clay	0.7	88.8	89.5%	84%	Above Max.
Kamuli Brown Clay	1.2	88.2	89.4%	84%	Above Max.
Kamuli light grey Clay	0.8	68.4	69.2%	84%	Below minimum
Kamuli dark grey Clay	0.6	98.7	99.3%	84%	Above Max.

From Table 4.2 it is seen that the percentage sum of Aluminate and Silicon dioxide is above the maximum required for the clay to give quality bricks.

4.3 Analysis and discussion of natural clay of the percentage content of Al_2O_3 , Fe_2O_3 , SiO_2 and CaO

A suitable earth for brick making should have various constituents in the following proportions:

(i) Alumina

Alumina- Al_2O_3 (22-32) % (Fernandes et.al., 2010). If the percentage of alumina is higher than 32 % the brick will shrink on drying and develop cracks. If the percentage is smaller the brick will not be moulded easily and nicely.

The test results as observed from Table 4.1, for alumina is between 0.3 to 1.7% for clay from Lira, between 0.7 to 1.1% for clay from Mukono and between 0.6 to 1.2 % for clay from Kamuli indicating non-compliance for the ideal range of the clay that is mined and used directly for manufacture of bricks.

(ii) Silica

Silica- SiO_2 (53-61) % (Fernandes et.al., 2010). However, (Chidiac et.al., 2007) recommends a silicon dioxide content of between 55-70% as ideal. The total percentage sum for the silica and aluminate ranges from 75% to 84% by weight of the raw clay materials (Federico et.al., 2005). Silica exists in two forms that is combined (bonded- $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) as constituent of clay and that exists as free silica (sand or quartz). Silicate is responsible for strength, hardness and resistance to shrinkage and shape of the brick and to a great extent for its durability or long life (Fernandes et.al., 2010). Too much free sand in the brick making earth raises the proportion of silica that makes the resulting manufactured brick brittle and porous.

The test results as observed from Table 4.1 for silica is between 90 to 92.5% for clay from Lira, between 86.1 to 91.2% for clay from Mukono and between 68.4 to 98.7 % for clay from Kamuli indicating non-compliance for the ideal range of the clay that is mined and directly used for manufacture of bricks.

(iii) Lime

Lime-CaO ($\leq 4\%$) i.e., 4% maximum (Chidiac et.al., 2005). Lime makes burning and hardening of bricks quicker and therefore is considered desirable. Lime is not required to be more than 4% because it causes excessive softening of bricks on heating. Lime and magnesium acts as fluxes. During brick making lime must be present in finely powdered and thoroughly dispersed form. If lime is present in nodules or grains it gets slaked (heated) (Chidiac et.al., 2005). If a brick is with this kind of lime is used, it gets easily hydrated and causes disintegration of the brick.

The test results as observed from Table 4.1 for lime is between .09 to 1.3% for clay from Lira, between 0.2 to 1.9 % for clay from Mukono and between 0.1 to 0.9 % for clay from Kamuli indicating compliance for the ideal range of the clay that is mined and directly used for manufacture of bricks

(iv) Iron oxide- Fe_2O_3

Iron oxide- Fe_2O_3 (4-6) % (Chidiac et.al., 2005). Iron oxide also acts as flux i.e., it lowers down the softening temperature of silica. Iron oxide has an additional function of imparting colour to the brick. The excess of this iron makes the brick too soft during burning imposing a risk of deformation in shape. Lack of iron oxide in the earth affect the final colour of the brick instead the brick may be yellow or light red.

The test results as observed from Table 4.1 for Fe_2O_3 is between 0.5 to 1.5% for clay from Lira, between 0.6 to 1.8% for clay from Mukono and between 0.4 to 0.9 % for clay from Kamuli indicating non-compliance for the ideal range of the clay that is mined and directly used for manufacture of bricks. It is also observed in Table 4.2 that the total sum of aluminate and silicon dioxide for eight samples are above the required maximum total sum of 84% and one sample is below the required minimum total sum of 75%. It confirms that the raw clay is impure for use in the making of bricks that is required for stability, durability and strength due to high amounts of silicon in them.

Table 4.3 Percentage content of Al_2O_3 , Fe_2O_3 , SiO_2 and CaO in purified clay

Sample Name	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	SiO_2 (%)
Lira Brown Clay	2.95	1.66	0.1	76.7
Lira Light Grey Clay	2.63	1.66	0.04	80.4
Lira Dark Grey Clay	2.02	1.41	0.04	95.98
Mukono Brown Clay	2.42	3.73	0.09	89.3
Mukono Light Grey Clay	1.5	1.73	0.06	79.4
Mukono Dark Grey Clay	1.99	2.04	0.01	83.7

Table 4. 4 : Percentage sum of Aluminate and Silicon dioxide in purified samples

Sample Name	Al ₂ O ₃ (%)	SiO ₂ (%)	Percentage sum of aluminate silicon dioxide	Acceptable range (75-84%) (Federico et.al., 2005, Fernandes et.al., 2010)	Remarks
Lira Brown Clay	2.95	76.7	79.65	75-84%	Btn 75-84(ok)
Lira Light Grey Clay	2.63	80.03	83.03	75-84%	Btn 75-84(ok)
Lira Dark Grey Clay	2.02	95.98	98	75-84%	Above 84 (not ok)
Mukono Brown Clay	2.42	89.3	91.72	75-84%	Above 84% (not ok)
Mukono light grey Clay	1.5	79.4	80.9	75-84%	Btn 75-84(ok)
Mukono dark grey Clay	1.99	83.7	85.69	75-84%	(ok)

Table 4.4 shows the results of simple purification of clay. It is seen that Lira brown clay, Lira light grey, Mukono light grey and Mukono dark clay content were within the acceptable range after purification.

Table 4. 5 Effect of purification on the content of natural clay

Sample Name	Chemical Name	% Composition in natural state	% Composition after purification	% Acceptable range For ideal industrial manufacture of clay bricks (Chediac et. al., 2007, Fernandes et.al., 2010)
Lira Light grey clay	Al ₂ O ₃	2.2	2.63	22-32
	Fe ₂ O ₃	1.1	1.66	4-6
	SiO ₂	85	80.4	53-61
	CaO	0.6	0.04	≤4
Lira dark grey clay	Al ₂ O ₃	0.3	2.02	22-32
	Fe ₂ O ₃	0.5	1.41	4-6
	SiO ₂	92.5	95.98	53-61
	CaO	0.09	0.04	≤4
Lira brown clay	Al ₂ O ₃	1.7	2.95	22-32
	Fe ₂ O ₃	1.5	2.55	4-6
	SiO ₂	90	76.7	53-61
	CaO	1.3	0.1	≤4
Mukono Light grey clay	Al ₂ O ₃	1.1	1.5	22-32
	Fe ₂ O ₃	1.6	1.73	4-6
	SiO ₂	86.1	79.4	53-61
	CaO	0.5	0.06	≤4
Mukono dark grey clay	Al ₂ O ₃	0.7	1.99	22-32
	Fe ₂ O ₃	0.6	2.04	4-6
	SiO ₂	88.8	83.7	53-61
	CaO	1.9	0.01	≤4
Mukono brown clay	Al ₂ O ₃	0.9	2.42	22-32
	Fe ₂ O ₃	1.8	3.73	4-6
	SiO ₂	91.2	89.3	53-61
	CaO	0.2	0.09	≤4

The effect of purification was to increase the percentage of Fe_2O_3 and Al_2O_3 , much as they did not hit the required range and to reduce the SiO_2 and CaO , although it did not hit the required range.

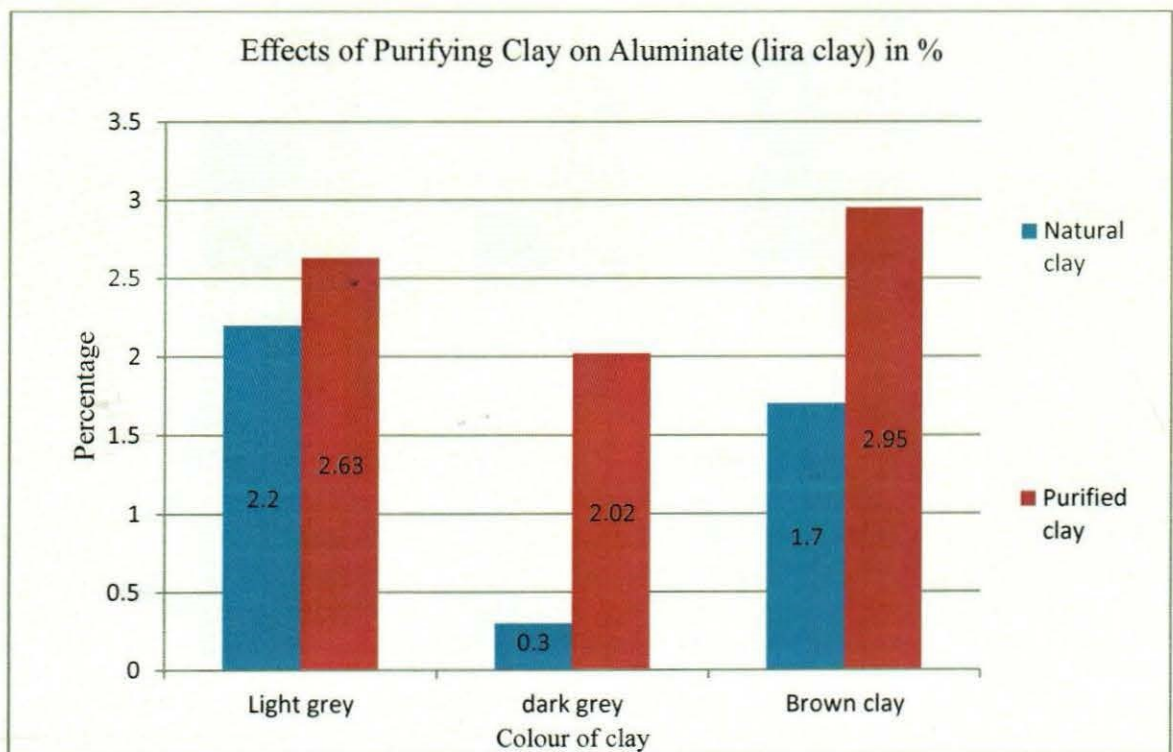


Figure 4. 1 : Effects of purifying clay on Aluminate (Lira clay) in percentage

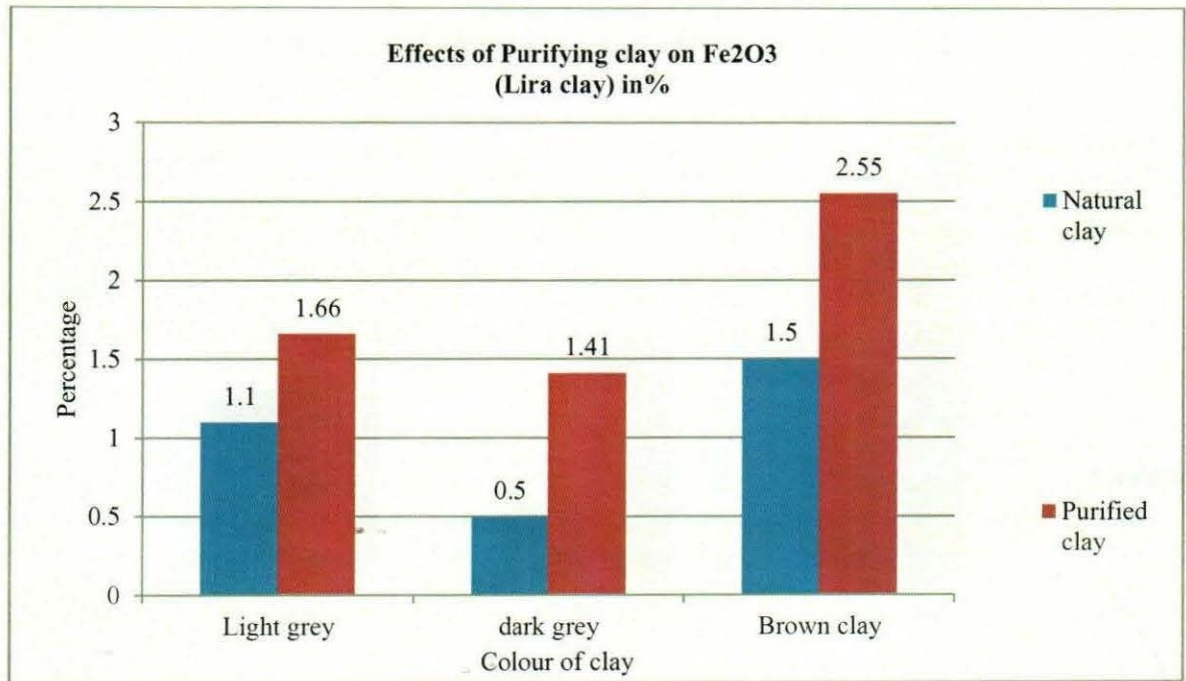


Figure 4. 2 : Effects of purifying clay on Fe₂O₃ (Lira clay) in percentage

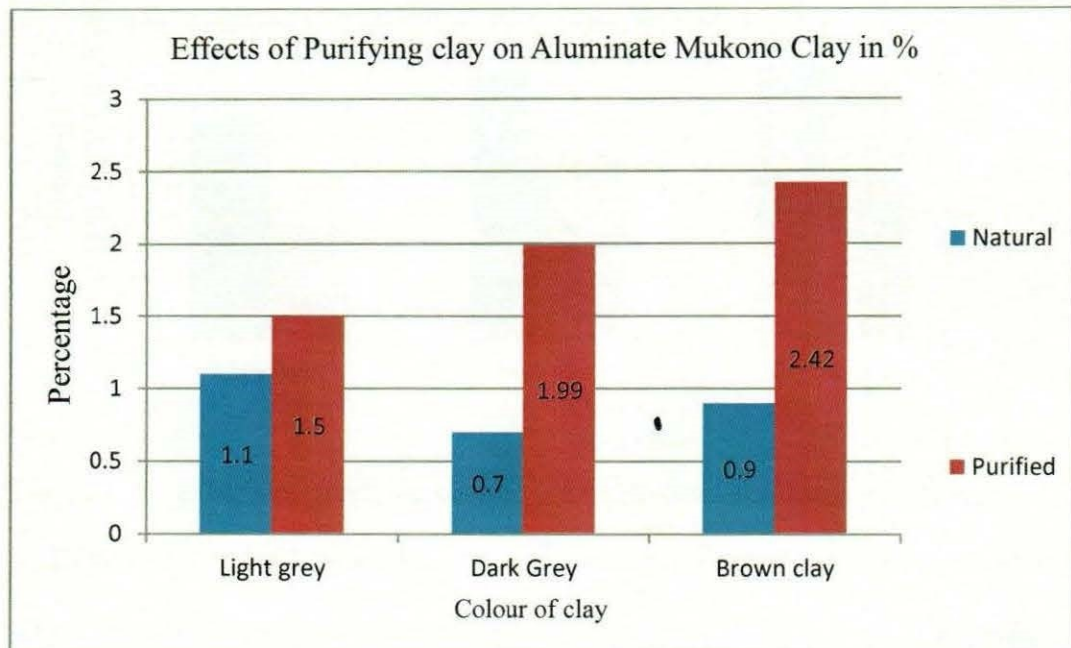


Figure 4. 3 : Effects of purifying clay on Aluminate (Mukono clay) in percentage

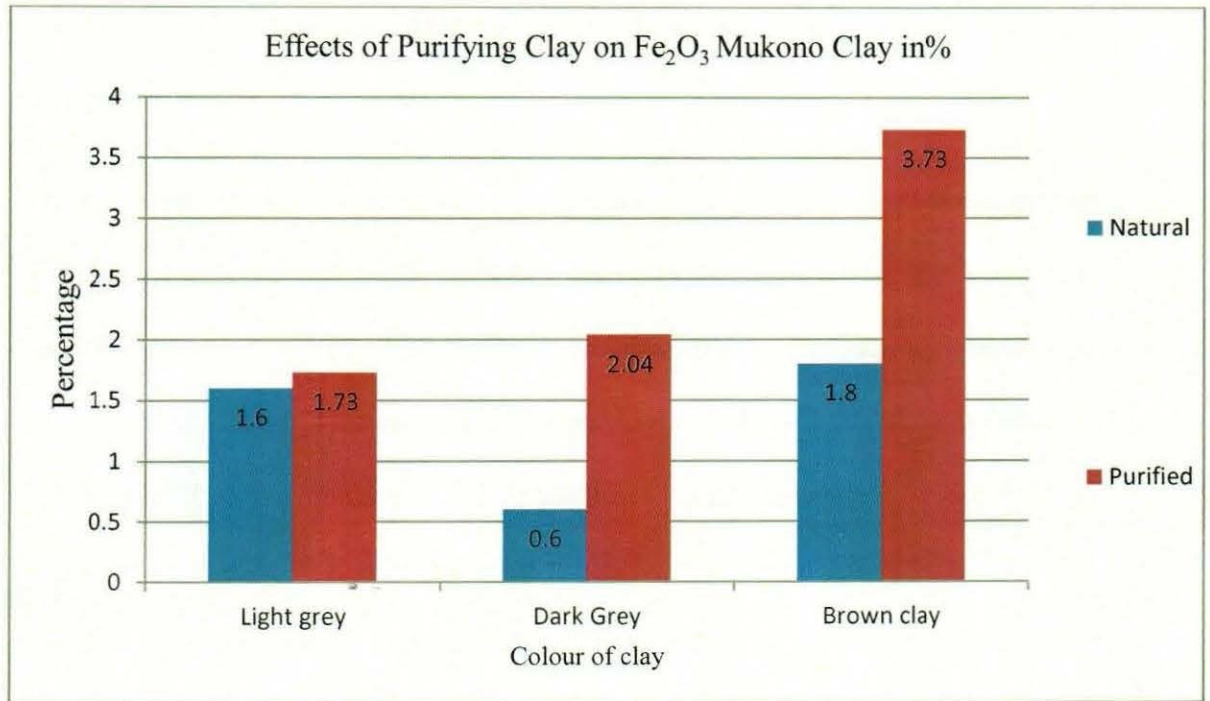


Figure 4. 4 : Effects of purifying clay on Fe_2O_3 (Mukono clay) in percentage

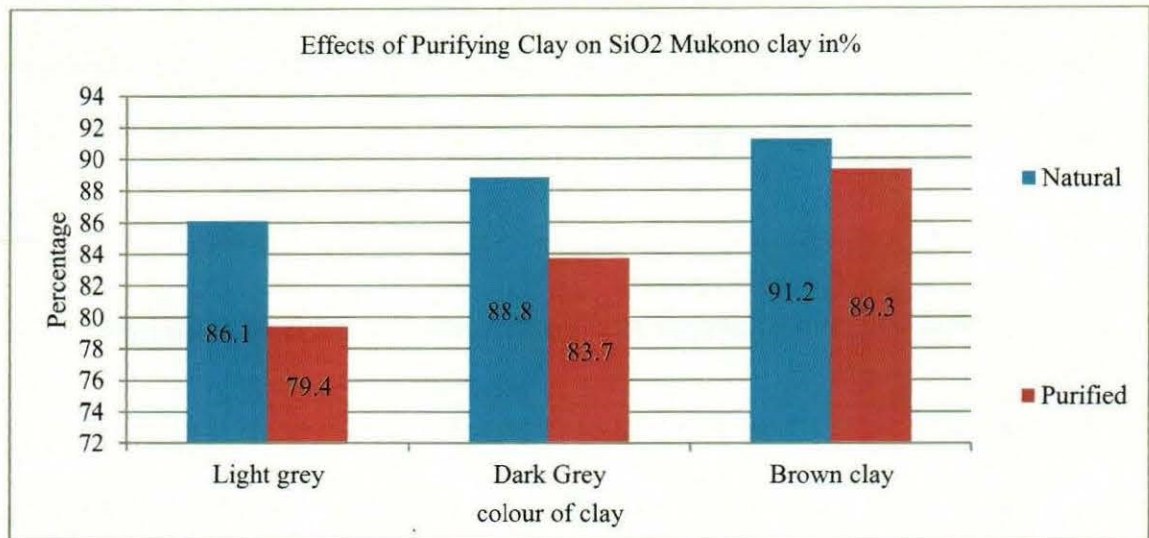


Figure 4. 5 : Effects of purifying clay on SiO_2 (Mukono clay) in percentage

In Table 4.3, 4.5 and Figures 4.1- 4.5 it was observed that after purification process, Al_2O_3 and Fe_2O_3 increased in percentage as compared to what existed in its natural state. It was found that the purification process tends to shift the clay to better line

state of its alumina and iron oxide as regards the brick manufacturing requirement compared to its state in raw form.

It was also observed that SiO_2 and CaO decreased in percentage as compared to what existed in its natural form. Purification tends to remove the un bonded or free sand (SiO_2)/quartz and CaO tends to disassociate after dissolving and remain as $\text{Ca}(\text{OH})_2$ in the water. This process shifts the high levels of both SiO_2 and that of CaO to low levels which are good in the brick manufacturing. The purification process did not exactly match the constituents as is required for an ideal clay for manufacture of ideal brick but it shifted the clay to better direction than the raw clay i.e. reducing free sand that would impart to the manufactured brick brittleness and porousness, that calcium oxide that would render the brick easily hydrated and cause disintegration and it made the aluminate increase for better plasticity and increased Iron oxide for lowering down the softening temperature and impart a good red colour.

4.4 Presentation, analysis and discussion for compressive strength tests

Compressive test results for Artisan common clay brick, bricks made with improved molding methods and with purification are given in the appendix.

Table 4. 6 : Comparison of characteristic strengths of Lira Bricks

Name of region	Type of brick	Characteristic strengths
Lira	Improved chemical composition artisan	2.0
	Improved mold brick	3.3
	Artisan	0.632

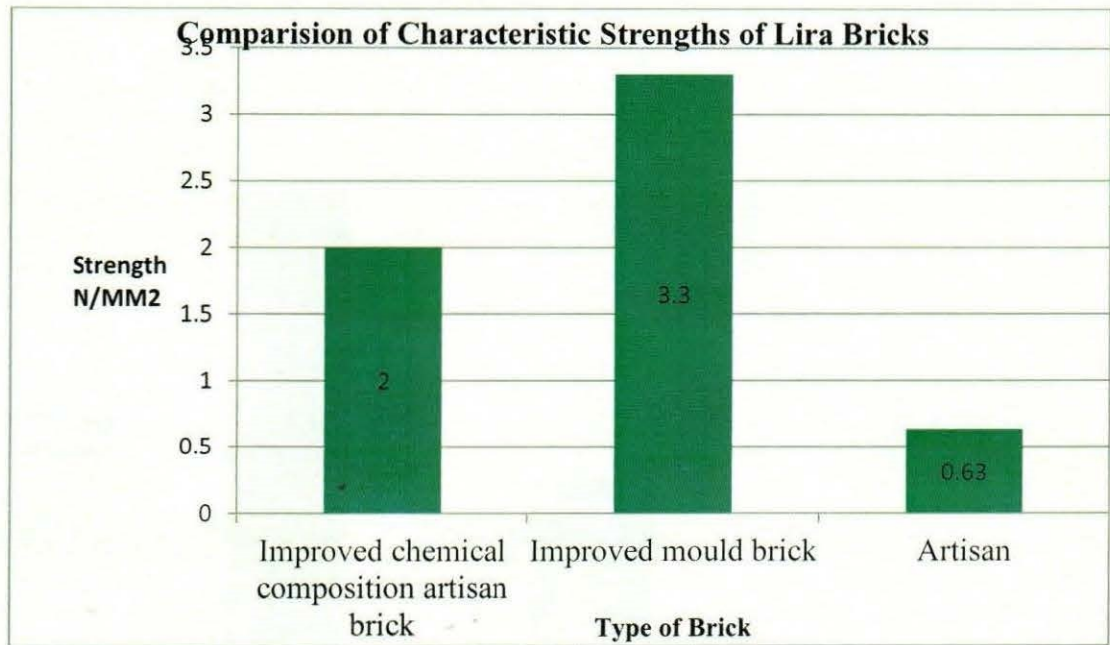


Figure 4.6 : Characteristic strength comparison of bricks from Lira

Table 4.7 : Comparison of characteristic strengths of bricks from Mukono

Name of region	Type of brick	Characteristic strengths
Mukono	Improved chemical composition artisan	5.12
	Improved mold brick	2.62
	Artisan	0.38

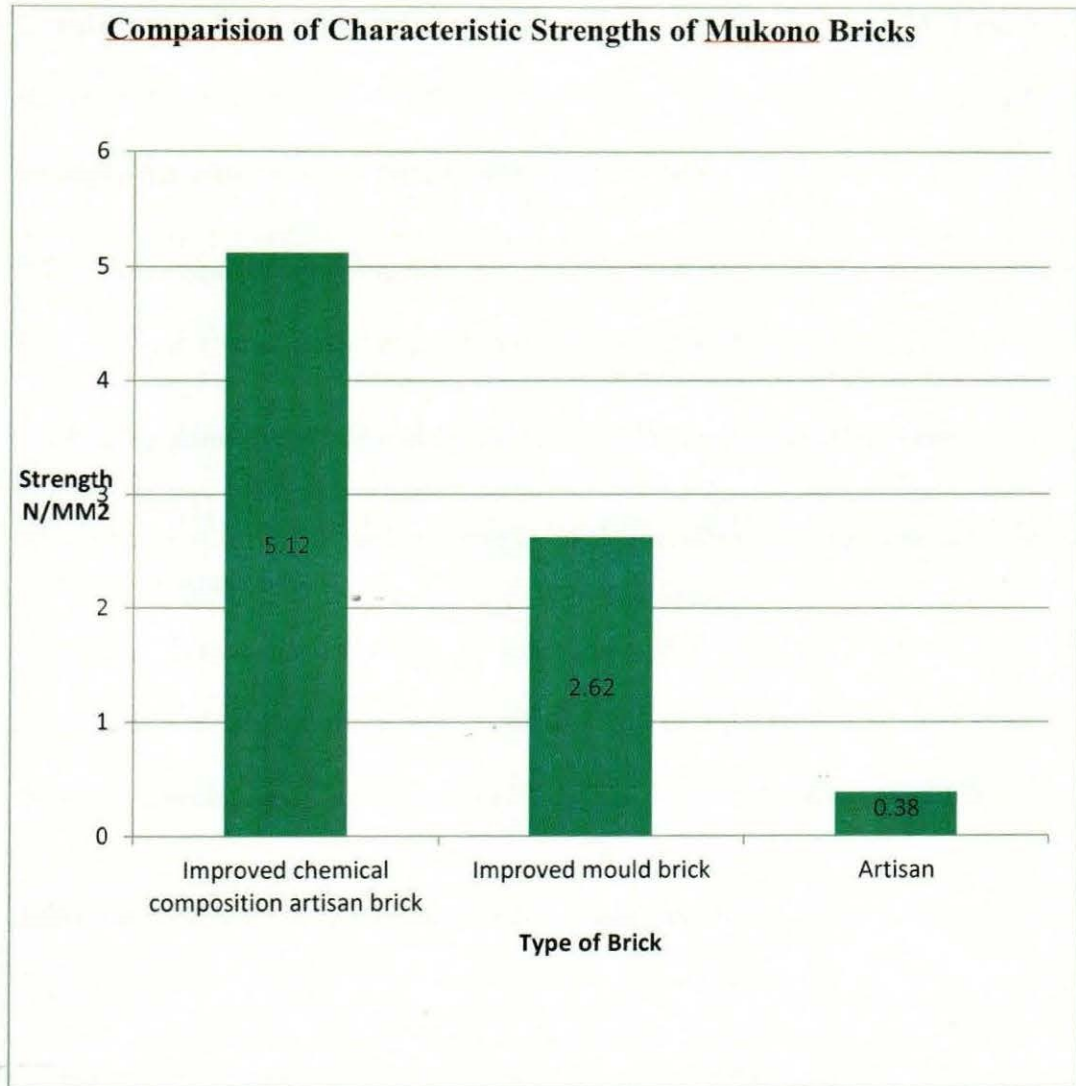


Figure 4.7 : Characteristic strength comparisons of bricks from Mukono

Comparisons of the characteristic's strengths of both the Lira and Mukono bricks shows that the method of purifying clay and use of improved molding of bricks increases the compressive strength of the artisan brick.

It therefore requires purifying clay and use the constant force clay pressing molding, for maximum characteristic strength production of the artisan clay brick.

4.5 Presentation, Analysis and Discussion for Water Absorption Tests

Absorption test results for artisan, improved chemical units for Mukono and Lira are given in the Appendix.

When clay bricks are subjected to water absorption for classification, class one brick does not absorb more than a sixth ($1/6$) of its dry weight and class two does not absorb more than a quarter ($1/4$) of its dry weight (Khanna, 2008)

Table 4.8 : Effect of purification on water absorption of natural Clay Lira

Type of brick	Water absorption %	Brick classification
Lira Artisan	16.69	2
Improved chemical light grey clay unit Lira	16.20	1
Improved chemical brown clay unit Lira	14.4	1
Improved chemical dark grey clay unit Lira	17.7	2

The effect of purification on the Lira natural clay was to reduce the water absorption on the light grey and brown clay and on dark grey clay, absorption increased.

Table 4.9 : Effect of purification on water absorption of natural clay Mukono

Type of brick	Water absorption %	Brick classification
Mukono Artisan	12.64	1
Improved chemical light grey clay unit Mukono	13.40	1
Improved chemical light brown clay unit Mukono	13.20	1
Improved chemical Dark grey clay unit Mukono	28.10	2

The effect of purification on the Mukono light grey and brown natural clay was not significant however, there was significant absorption of water of the dark grey clay

4.6 Presentation, analysis and discussion for efflorescence tests

After 24 hours of immersion in water the bricks were placed in a well-ventilated room in which the monitoring was done for eight weeks. After 8 weeks it was seen as shown in table 4.10 and table 4.11.

Table 4.10 : Efflorescence results on Artisan, Improved chemical composition artisan and Improved mold bricks of Mukono

Item	Description	Area of brick surface (mm ²)	Area seen with whitish/gr eyish shades	Percentage of area of brick with efflorescence effect	Result of efflorescence (Dhir,1996, Khan,2008)
1	Mukono artisan brick	29400	4500	15.30%	Moderate
2	Improved chemical artisan brick Mukono	3848.5	2475	12.3%	Moderate
3	Improved mold brick Mukono	19270	2696.4	14%	Moderate

The effects of purification on the Mukono clays, was that efflorescence reduced i.e., from 15.3% to 12.3 %

Table 4.11 : Efflorescence results on Artisan, Improved chemical composition Artisan and Improved mold Bricks of Lira

Item	Description	Area of brick surface (mm ²)	Area seen with whitish/greyish shades	Percentage of area of brick with efflorescence effect	Result of efflorescence
1	Lira artisan brick	20,000	4000	20%	Moderate
2	Improved chemical artisan brick Lira	3848.5	225	6%	Slight
3	Improved mold brick Lira	19260	2899	15%	Moderate

The effect of purification on the Lira clays, was that efflorescence reduced i.e. from 20% to 6%.

The efflorescence test results gave an indication that the alkalis present in all the three brick types is not serious and dangerous.

For efflorescence regarded as nil is when there are no noticeable deposits of efflorescence. For area to be less than 10% of exposed area of brick when covered by a thin layer of salt is taken as slight. When the deposits are between 10 to 50% is moderate, when area is 50% or more of the exposed surface but not accompanied by powdering and flaking is heavy but raked serious when 50% and more are powdered and flaked surface is seen.

Observations were made on the units on the artisan and improved chemical artisan brick and seen that the improved chemical artisan brick has less coverage of the salt migrations. This is an indication that purification does the disassociation of the alkalis and remains in the water as hydroxides which is good for brick manufacturing since alkalis when incorporated in the earth brick making, results in absorbing water leading to easy disintegration of bricks.

4. 7 Results of Artisan brick manufacturing process in Uganda

After compiling the results on the form for interview, deductions were made and found out that the experienced clay brick making artisans do operate as follows:

- i. visual identification of clay deposits in the area of operation
- ii. mining of clay from clay deposits areas and heaping the mined clay.
- iii. tempering of clay
- iv. molding of brick units
- v. drying of molded brick

- vi. burning of bricks and cooling

4.7.1 Visual clay identification

They do normally identify clay in lower plain areas of the swamp places as fine grained and sticky soils that get stuck in clothes and difficult to remove when wet but can be scraped when dry.

4.7.2 Clay mining

The selected area for clay mining is first cleaned or unsoiled at the top to remove most of the undesirable top soils which is always rich in pebbles and organic matters. Clay is mined by use of hand tools like spades, shovels, hoes and is placed in heaps for some days for it to dissipate the excess water it is mined with. Usually, the time allowed is between 3 to 7 days depending on the water content in the clay.

4.7.3 Tempering of clay

This is the converting of the mined clay into homogeneous mix of the desired plasticity by mixing it thoroughly with proper quantities of water. This process is done manually. Clay is thoroughly kneaded under feet of workers with gradual addition of water till desired homogeneity and plasticity is obtained.

4.7.4 Molding of bricks

Molding is the process of making properly shaped bricks units from thoroughly tempered clay. In Uganda molding is done using hand molding. The quality of the tempered clay is made soft so that it can be molded into the required shapes conveniently. The brick is shaped from tempered clay and filled into the mold with little effort of pressing the clay into the mold on a table as shown in Figure 4.8.

There after the molded brick is transferred to a leveled prepared ground using a wooden mold to make up green bricks.



Figure 4.8: Artisan method of brick molding

Source: (Mbarara-Mukono artisan brick making area)

4.7.5 Drying of molded brick (green bricks)

On removal from the mold the brick is rested on the largest plane for about 3 days and then changed to the smallest plane for about 4 days there after the bricks are stacked in an orderly format under a shade leaving gaps for aeration. In the shade, is where the green bricks gain strength before they become ready for firing or burning. After gain of strength and drying under the shade, the green bricks are stack in clamp style as shown in the field kiln for burning.



Figure 4.9: Field Kiln for burning of bricks and cooling

Source: (Mbarara-Mukono artisan brick making area)

After stacking the green bricks in a field kiln as shown in Figure 4.9, the fuel in form of firewood or agriculture waste e.g., coffee husks, rice husks, wood dust, fire wood etc. are fed in the openings created in the field kiln.

The field kilns are either rectangular or square. The sizes of the kiln around Mukono are between 2.1 to 3.0 meters in width and 3.5 to 6.0metres in length. After feeding in either the husks or the fire wood then energized the fire for the firing to take place. At the beginning of firing, the wet grass is placed at the top of the field kiln. The firing time is prolonged until the wet grass at the top is burnt to ash. After the grass has got burnt, the openings in the field kiln are closed by use of mud mortar and the broken bricks, the sides of the field kiln also are covered by the mud mortar to avoid the loss of the heat.

CHAPTER FIVE:

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The objective of this research; assessment of artisan clay bricks on performance of structural strength, chemical stability and durability in Uganda was accomplished;

- Determined the natural chemical percentage content of (Al_2O_3 , SiO_2 , Fe_2O_3 and CaO) of locally used clay by the artisans, in manufacturing bricks in Uganda and found out that natural clay cannot make an ideal strong, chemically stable and durable brick unless is purified.
- Found out that improvement on the percentage chemical content of (Al_2O_3 , SiO_2 , Fe_2O_3 and CaO) composition ratios as related to the ideal composition for quality industrial ceramic manufacturing is done through slurry fractionation.
- Established new methods of manufacturing improved artisan clay brick to meet specific characteristics properties of producing durable, chemically stable and structural strength burnt clay brick by including both slurry fractionating and use of constant pressing type of molding during the artisan clay brick manufacturing.
- Established that the present manufacturing process used by the artisans in the manufacture of local clay bricks in Uganda done in sequential order as follows: -
 - i. visual identification of clay deposits in the area of operation
 - ii. mining of clay from clay deposits areas and heaping the mined clay.

- iii. tempering of clay
- iv. molding of brick units
- v. drying of molded brick

- Vi. burning of bricks and cooling

The manufacturing process (methods) used by the artisans in Uganda was found not effective for brick performance of structural strength, chemical stability and durability. It requires interventions for improvement.

5.2 RECOMMENDATIONS

- Historical methods of brick artisan manufacturing processes were obtained from three regions of Uganda. It is recommended for clay brick artisans to include raw clay refining before molding of clay brick for purposes of improving on the clay chemical structure to avoid unbounded sand, much alkalis, little aluminate and iron oxide.
- Change the type of mold used by the artisan to constant force kneaded clay pressing mold that imparts uniform compaction during manufacturing.
- Ugandan government through its agents to enforce the artisan to refine clay, during brick manufacturing and change the molding style to adopt constant clay pressing molding to produce good quality clay brick of at least 3.5N/mm^2 to enable the structure engineers take use of artisan bricks for structural specifications/design.
- Ugandan government through its agents to map out the areas of kaolinite ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) clay in every sub-county to help artisan access right clay for brick making.
- Recommend further research on clay for production of structural prestressed sections and medicinal activities on skin diseases.

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APPENDIX I:

SUMMARY RESULTS OF LABORATORY CLAY CHEMICAL ANALYSIS

Results for Natural Clay Occurring Minerals

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College of Natural Sciences
 School of Physical Sciences

DEPARTMENT OF GEOLOGY AND PETROLEUM STUDIES

17/9/2019

Mr. Nabbala Moses Mumpembe

Dear Sir

RE: ANALYSIS OF CLAY SAMPLES

The Department received nine clay samples in the laboratory to be analyzed for Al_2O_3 , Fe_2O_3 , SiO_2 and CaO. During analysis, the samples were ground then digested with aqua regia. The resultant solution/digest was analyzed using an atomic absorption spectrophotometer (Agilent 240FS AA), the results below expressed in parts per million (ppm) and percentage were obtained.

Sample Name	Al_2O_3 (ppm)	Al_2O_3 (%)	Fe_2O_3 (ppm)	Fe_2O_3 (%)	CaO (ppm)	CaO (%)	SiO_2 (%)
Lira Light Grey Clay	22280.59	2.2	11194.83	1.1	5736.69	0.6	85.0
Mukono Light Grey Clay	11497.95	1.1	15502.82	1.6	4801.15	0.5	86.1
Lira Dark Grey Clay	3008.80	0.3	5379.09	0.5	894.56	0.09	92.5
Kamuli Brown Clay	12686.92	1.2	8656.41	0.9	7466.67	0.7	88.2
Lira Brown Clay	17194.14	1.7	14956.15	1.5	13168.99	1.3	90.0
Mukono Brown Clay	9214.02	0.9	18326.61	1.8	2088.20	0.2	91.2
Kamuli Dark Grey Clay	6086.30	0.6	3681.57	0.4	1002.77	0.1	98.7
Kamuli Light Grey Clay	8191.01	0.8	2759.13	0.3	8726.62	0.9	68.4
Mukono Dark Grey Clay	6999.93	0.7	5799.11	0.6	18546.34	1.9	88.8

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Results for Purified Clay Occurring Minerals

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College of Natural Sciences
School of Physical Sciences
DEPARTMENT OF GEOLOGY AND PETROLEUM STUDIES

 22/7/2020

Mr. Nabbala Moses Mumpembe

Dear Sir,

RE: ANALYSIS OF CLAY SAMPLE

The Department received six clay samples in the laboratory to be analysed for Fe₂O₃, Al₂O₃, CaO and SiO₂. During analysis the sample ground to fine powder and digested with aqua regia and the digested analysed using an atomic absorption spectrophotometer (Agilent AA240FS) for Fe, Al, and Ca. Silica was determined gravimetrically The results below expressed in percentage million were obtained.

SAMPLE	Fe ₂ O ₃ %	Al ₂ O ₃ %	CaO%	SiO ₂ %
Light grey Mukono	1.73	1.5	0.06	79.4
Brown clay Mukono	3.76	2.42	0.09	89.3
Dark grey Lira	1.41	2.02	0.04	95.98
Dark grey Mukono	2.04	1.99	0.01	83.7
Light grey Lira	1.66	2.63	0.04	80.4
Brown Clay Lira	2.55	2.95	0.10	76.7

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APPENDIX II:

SUMMARY RESULTS FOR LABORATORY COMPRESSIVE TESTS

Compressive Tests Results for Artisan Common Clay Brick from Lira

Item	Size of brick(mm)	Weight of brick(kg)	Area of brick (mm ²)	Compressive crushing force read x1000N	Ultimate compressive strength (N/mm ²)	Average compressive strength (N/mm ²)
1	210x135	3.4	28,350	58.60	2.06	
2	210x135	3.2	28,350	29.50	1.04	
3	210x135	3.0	28,350	35.29	1.24	1.30
4	210x135	3.4	28,350	38.28	1.35	
5	210x135	3.2	28,350	23.49	0.83	

Characteristic strength of artisan clay brick from Lira is 0.63N/mm^2 as calculated in appendix III

Compressive Tests Results for Improved Moldings Brick from Raw Clay Lira

Item	Size of brick	Weight of the brick(kg)	Area of brick(m ²)	Compressive crushing force read x1000N	Ultimate compressive strength (N/mm ²)	Average compressive strength(N/mm ²)
1	180x107	2.0	19260	131	6.8	
2	180x107	2.3	19260	93	4.8	
3	180x107	2.3	19260	65.5	3.4	4.8
4	180x107	2.3	19260	95	4.9	
5	180x107	2.3	19260	80	4.2	

Characteristic strength of improved moldings brick from raw clay Lira is 3.3N/mm^2 as calculated in appendix III.

Compressive Tests Results for Artisan Common Clay Brick from Mukono

Item	Size of brick	Weight of the brick(kg)	Area of brick(mm ²)	Compressive crushing force read x1000N	Ultimate compressive strength (N/mm ²)	Average compressive strength(N/mm ²)
1	200x110	3.8	22,000	14.7	0.67	
2	200x110	3.4	22,000	35	1.59	
3	200x110	3.1	22,000	19.4	0.88	1.62
4	200x110	2.8	22,000	50	2.27	
5	200x110	3.8	22,000	58.9	2.68	

Characteristic strength of artisan clay brick from Mukono is 0.38N/mm^2 as calculated in appendix III

Compressive Tests Results for Improved Molding Brick from Raw Clay Mukono

Item	Size of brick	Weight of the brick(kg)	Area of brick(mm ²)	Compressive crushing force read x1000N	Ultimate compressive strength (N/mm ²)	Average compressive strength(N/mm ²)
1	180x107	2.0	19260	147.6	7.66	
2	180x107	2.0	19260	97.4	5.05	5.36
3	180x107	1.8	19260	64.9	3.36	

Characteristic strength of improved molding brick from raw clay Mukono is 2.62N/mm^2 as calculated in appendix III

Compressive Tests Results for Improved Chemical Composition Artisan Unit from Purified Lira Light Grey Clay

Item	Size of clay unit	Area of clay (mm ²)	Compressive crushing force read x1000N	Ultimate compressive strength (N/mm ²)	Average compressive strength (N/mm ²)
1	Ø 70mm&75mm thick	3848.45	10.3	2.68	
2	Ø 70mm&75mm thick	3848.45	10.6	2.75	2.75
3	Ø 70mm&75mm thick	3848.45	13.3	3.45	
4	Ø 70mm&75mm thick	3848.45	8.1	2.10	

Characteristic strength of improved chemical composition artisan unit from purified Lira light grey clay is 2.0N/mm² as calculated in appendix II.

Compressive Tests Results for Improved Chemical Composition Artisan Unit from Purified Lira Dark Grey Clay

Item	Size of clay unit	Area of clay unit (mm ²)	Compressive crushing force read x1000N	Ultimate compressive strength (N/mm ²)	Average compressive strength (N/mm ²)
1	Ø 70mm&75mm thick	3848.45	3.3	0.86	
2	Ø 70mm&75mm thick	3848.45	3.8	0.99	
3	Ø 70mm&75mm thick	3848.45	1.5	0.39	0.7
4	Ø 70mm&75mm thick	3848.45	3.2	0.83	
5	Ø 70mm&75mm thick	3848.45	1.6	0.42	

Compressive Tests Results for Improved Chemical Composition Artisan Unit from Purified Lira Brown Clay

Item	Size of clay unit	Area of clay unit (mm ²)	Compressive crushing force read x1000N	Ultimate compressive strength (N/mm ²)	Average compressive strength (N/mm ²)
1	Ø 70mm&75mm thick	3848.45	10.7	2.78	
2	Ø 70mm&75mm thick	3848.45	6.6	1.72	2.13
3	Ø 70mm&75mm thick	3848.45	8.7	2.26	
4	Ø 70mm&75mm thick	3848.45	7.8	2.03	
5	Ø 70mm&75mm thick	3848.45	7.2	1.87	

Compressive Tests Results for Improved Chemical Composition Artisan Clay Unit from Purified Mukono Light Grey Clay

Item	Size of clay unit	Area of brick	Compressive crushing force read x1000N	Ultimate compressive strength (N/mm ²)	Average compressive strength (N/mm ²)
1	Ø 70mm&75mm thick	3848.45	13.1	3.4	
2	Ø 70mm&75mm thick	3848.45	19.6	5.10	4.52
3	Ø 70mm&75mm thick	3848.45	16.0	4.16	
4	Ø 70mm&75mm thick	3848.45	20.8	5.41	

Our Ref: 0199-CONC/SEPT-2020

Test Certificate

DATE: 18/10/2020

COMPRESSIVE STRENGTH TEST

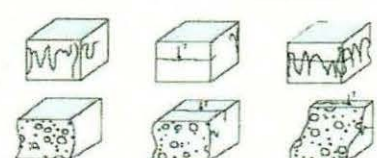
Test Method and Specification Reference : BS 3921:1985, BS 1881-116-1983, BS EN 1996-1-1, BS EN 772-1:2011, BS EN 771-1:2003, BS EN 772-7:1998, BS EN 772-3:1998.

PROJECT:	ACADEMIC RESEARCH - MSc		
CONTRACTOR:	N/A	CLIENT:	Nabbala moses Mumpembe
SPECIMEN DETAILS:			
SPECIMEN DIMENSION:	Ø 70x75 thick (mm)	Test area (mm²)	28.350
STRUCTURAL MEMBER:	Clay bricks	SOURCE MATERIAL:	Clay from Lira
DATE TESTED:	19/08/2020	ADMIXTURE ADDED:	NONE
		AGE:	N/A
LAB TECH: Emma. O			
Improved chemical composition unit from purified Lira brown clay			

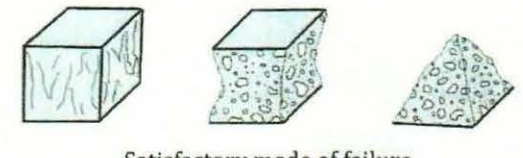
Specimen Label/Reference	Weight (Kg)	Density (Kg/m ³)	Maximum Load (KN)	Compressive Strength (MPa)	Mode Of Failure
1	-	-	10.7	2.78	Satisfactory / Unsatisfactory
2	-	-	6.6	1.72	Satisfactory / Unsatisfactory
3	-	-	8.7	2.26	Satisfactory / Unsatisfactory
4	-	-	7.8	2.03	Satisfactory / Unsatisfactory
5	-	-	7.2	1.89	Satisfactory / Unsatisfactory

FAILURE MODES

Unsatisfactory mode of failure



Satisfactory mode of failure



MACHINE SPEC:
CONTROLS, EN - WIZARD BASIC

REMARKS:

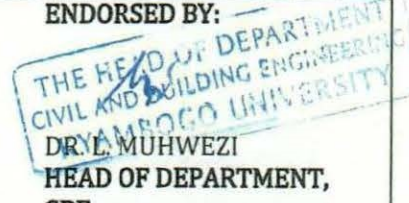
- Brick density and compressive strength calculated with volumes and areas of Nominal dimensions.
- Bricks were found with no defects

COMPILED BY:



P. OCHIENG
MATERIALS ENGINEER /
LAB MANAGER

ENDORSED BY:



THE HEAD OF DEPARTMENT
CIVIL AND BUILDING ENGINEERING
KYAMBOGO UNIVERSITY
DR. L. MUHWEZI
HEAD OF DEPARTMENT,
CBE

Our Ref: 0199-CONC/SEPT-2020

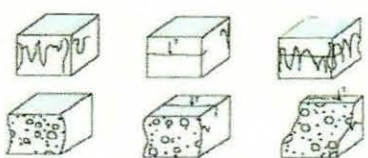
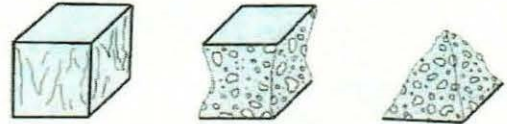

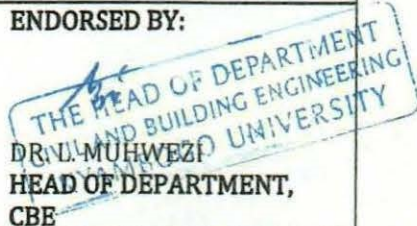
Test Certificate

DATE: 18/10/2020

COMPRESSIVE STRENGTH TEST

Test Method and
Specification Reference :

BS 3921:1985, BS 1881-116-1983, BS EN 1996-1-1, BS EN 772-1:2011, BS EN 771-1:2003, BS EN 772-7:1998, BS EN 772-3:1998.

PROJECT:		ACADEMIC RESEARCH - MSc			
CONTRACTOR:		N/A		CLIENT:	Nabbala moses Mumpembe
SPECIMEN DETAILS:					
SPECIMEN DIMENSION:			Ø 70x75 thick (mm)	Test area (mm²)	3848.45
STRUCTURAL MEMBER:			Clay bricks	SOURCE MATERIAL:	Clay from Lira
DATE TESTED:		19/08/2020	ADMIXTURE ADDED:	NONE	AGE: N/A
LAB TECH: Emma. O					
Improved chemical composition unit from purified Lira dark grey clay					
Specimen Label/Reference	Weight (Kg)	Density (Kg/m ³)	Maximum Load (KN)	Compressive Strength (MPa)	Mode Of Failure
1	-	-	3.3	0.86	Satisfactory / Unsatisfactory
2	-	-	3.8	0.99	Satisfactory / Unsatisfactory
3	-	-	1.5	0.39	Satisfactory / Unsatisfactory
4	-	-	3.2	0.83	
5	-	-	1.6	0.42	
FAILURE MODES					
<div style="display: flex; justify-content: space-around; align-items: center;"> <div style="text-align: center;"> <p>Unsatisfactory mode of failure</p>  </div> <div style="text-align: center;">  <p>Satisfactory mode of failure</p> </div> </div>					
MACHINE SPEC:			COMPILED BY:		ENDORSED BY:
CONTROLS, EN - WIZARD BASIC			 P. OCHIENG MATERIALS ENGINEER / LAB MANAGER		 THE HEAD OF DEPARTMENT CIVIL AND BUILDING ENGINEERING KYAMBOGO UNIVERSITY HEAD OF DEPARTMENT, CBE
REMARKS:					
<ul style="list-style-type: none"> Brick density and compressive strength calculated with volumes and areas of Nominal dimensions. Bricks were found with no defects 					

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Test Method and
Specification Reference :

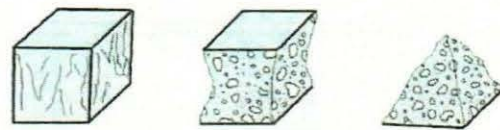
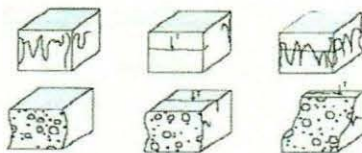
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PROJECT:	ACADEMIC RESEARCH - MSc		
CONTRACTOR:	N/A	CLIENT:	Nabbala moses Mumpembe
SPECIMEN DETAILS:			
SPECIMEN DIMENSION:	200x110 x 60 (mm)	Test area (mm²)	22,000
STRUCTURAL MEMBER:	Clay bricks	SOURCE MATERIAL:	Clay from Mukono
DATE TESTED:	19/08/2020	ADMIXTURE ADDED:	NONE
		AGE:	N/A
		LAB TECH: Emma. O	
Artisan common clay brick of Mukono			

Specimen Label/Reference	Weight (Kg)	Density (Kg/m ³)	Maximum Load (KN)	Compressive Strength (MPa)	Mode Of Failure
1	3.8	2879	14.7	0.67	Satisfactory / Unsatisfactory
2	3.4	2576	35.0	1.59	Satisfactory / Unsatisfactory
3	3.1	2348	19.4	0.88	Satisfactory / Unsatisfactory
4	2.8	2121	50.0	2.27	Satisfactory / Unsatisfactory
5	3.8	2879	58.9	2.68	Satisfactory / Unsatisfactory

FAILURE MODES

Unsatisfactory mode of failure



Satisfactory mode of failure

MACHINE SPEC:
CONTROLS, EN - WIZARD BASIC

REMARKS:

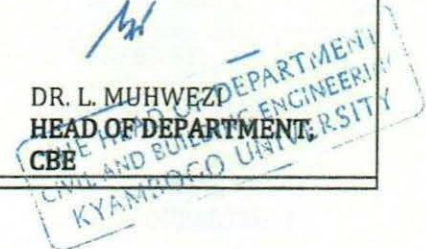
- Brick density and compressive strength calculated with volumes and areas of Nominal dimensions.
- Bricks were found with no defects

COMPILED BY:

P. OCHIENG
MATERIALS ENGINEER /
LAB MANAGER

ENDORSED BY:

DR. L. MUHWEZ
HEAD OF DEPARTMENT
CBE



Our Ref: 0199-CONC/SEPT-2020

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DATE: 18/10/2020

COMPRESSIVE STRENGTH TEST

**Test Method and
Specification Reference :**

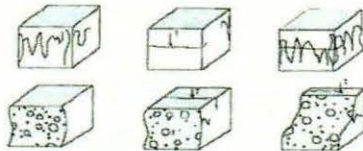
BS 3921:1985, BS 1881-116-1983, BS EN 1996-1-1, BS EN 772-1:2011, BS EN 771-1:2003, BS EN 772-7:1998, BS EN 772-3:1998.

PROJECT:	ACADEMIC RESEARCH - MSc		
CONTRACTOR:	N/A	CLIENT:	Nabbala moses Mumpembe
SPECIMEN DETAILS:			
SPECIMEN DIMENSION:	180x107x 60 (mm)	Test area (mm²)	28.350
STRUCTURAL MEMBER:	Clay bricks	SOURCE MATERIAL:	Clay from Mukono
DATE TESTED:	19/08/2020	ADMIXTURE ADDED:	NONE
		AGE:	N/A
LAB TECH: Emma. O			
Improved mold bricks from Mukono raw clay			



Specimen Label/Reference	Weight (Kg)	Density (Kg/m ³)	Maximum Load (KN)	Compressive Strength (MPa)	Mode Of Failure
1	1.9	1644	15.7	0.82	Satisfactory / Unsatisfactory
2	2.0	1731	147.6	7.66	Satisfactory / Unsatisfactory
3	3.0	2596	97.4	5.05	Satisfactory / Unsatisfactory
4	1.8	1558	64.9	3.36	Satisfactory / Unsatisfactory
5	2.0	1731	20.2	1.05	Satisfactory / Unsatisfactory

FAILURE MODES

Unsatisfactory mode of failure



Satisfactory mode of failure

<p>MACHINE SPEC: CONTROLS, EN - WIZARD BASIC</p> <p>REMARKS:</p> <ul style="list-style-type: none"> Brick density and compressive strength calculated with volumes and areas of Nominal dimensions. Bricks were found with no defects 	<p>COMPILED BY:</p> <p style="text-align: center;"></p> <p>P. OCHIENG MATERIALS ENGINEER / LAB MANAGER</p> <p>ENDORSED BY:</p> <div style="text-align: center;">  DR. L. MUHWEZI HEAD OF DEPARTMENT, CBE </div>
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Our Ref: 0199-CONC/SEPT-2020

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Test Method and
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EN 771-1:2003, BS EN 772-7:1998, BS EN 772-3:1998.

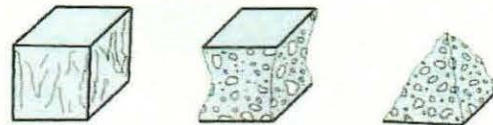
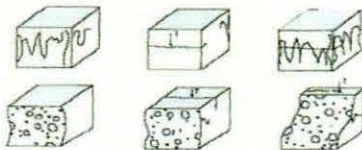
PROJECT:	ACADEMIC RESEARCH - MSc		
CONTRACTOR:	N/A	CLIENT:	Nabbala moses Mumpembe
SPECIMEN DETAILS:			
SPECIMEN DIMENSION:	Ø 70x75 thick (mm)	Test area (mm²)	3848.45
STRUCTURAL MEMBER:	Clay bricks	SOURCE MATERIAL:	Clay from Mukono
DATE TESTED:	19/08/2020	ADMIXTURE ADDED:	NONE
		AGE:	N/A
		LAB TECH: Emma O	

Improved chemical composition unit from purified Mukono light grey clay

Specimen Label/Reference	Weight (Kg)	Density (Kg/m ³)	Maximum Load (KN)	Compressive Strength (MPa)	Mode Of Failure
1	-	-	13.1	3.4	Satisfactory / Unsatisfactory
2	-	-	8.7	2.26	Satisfactory / Unsatisfactory
3	-	-	19.6	5.10	Satisfactory / Unsatisfactory
4	-	-	16.0	4.16	Satisfactory / Unsatisfactory
5	-	-	19.2	5.41	Satisfactory / Unsatisfactory

FAILURE MODES

Unsatisfactory mode of failure



Satisfactory mode of failure

MACHINE SPEC:

CONTROLS, EN - WIZARD BASIC

REMARKS:

- Brick density and compressive strength calculated with volumes and areas of Nominal dimensions.
- Bricks were found with no defects

COMPILED BY:

P. OCHIENG
MATERIALS ENGINEER /
LAB MANAGER

ENDORSED BY:

DR. L. MUHWEZI
HEAD OF DEPARTMENT,
CBE

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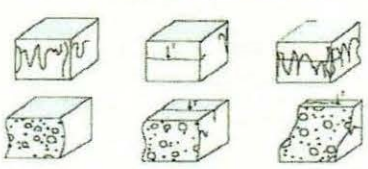



Test Certificate

DATE: 18/10/2020

COMPRESSIVE STRENGTH TEST

Test Method and
Specification Reference :

BS 3921:1985, BS 1881-116-1983, BS EN 1996-1-1, BS EN 772-1:2011, BS EN 771-1:2003, BS EN 772-7:1998, BS EN 772-3:1998.

PROJECT:	ACADEMIC RESEARCH - MSc				
CONTRACTOR:	N/A	CLIENT:	Nabbala moses Mumpembe		
SPECIMEN DETAILS:					
SPECIMEN DIMENSION:	Ø 70x75 thick (mm)	Test area (mm²)	3848.45		
STRUCTURAL MEMBER:	Clay bricks	SOURCE MATERIAL:	Clay from Lira		
DATE TESTED:	19/08/2020	ADMIXTURE ADDED:	NONE	AGE:	N/A
LAB TECH: Emma. O					
Improved chemical composition unit from purified Mukono brown clay					
Specimen Label/Reference	Weight (Kg)	Density (Kg/m ³)	Maximum Load (KN)	Compressive Strength (MPa)	Mode Of Failure
1	-	-	18.2	4.7	Satisfactory / Unsatisfactory
2	-	-	29.1	7.56	Satisfactory / Unsatisfactory
3	-	-	35.9	9.33	Satisfactory / Unsatisfactory
4	-	-	31.8	8.26	Satisfactory / Unsatisfactory
5	-	-	32.4	8.4	Satisfactory / Unsatisfactory
FAILURE MODES					
Unsatisfactory mode of failure					
					
Satisfactory mode of failure					
					
MACHINE SPEC:	CONTROLS, EN - WIZARD BASIC		COMPILED BY:	ENDORSED BY:	
REMARKS:	<ul style="list-style-type: none"> Brick density and compressive strength calculated with volumes and areas of Nominal dimensions. Bricks were found with no defects 		 P. OCHIENG MATERIALS ENGINEER / LAB MANAGER	 DR. L. MUHWEZI HEAD OF DEPARTMENT, CBE	

Our Ref: 0199-CONC/SEPT-2020

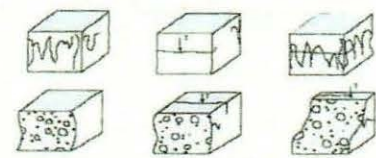


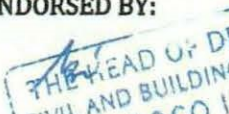
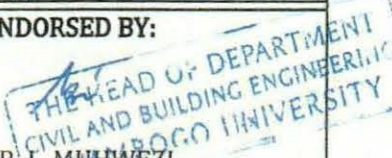
Test Certificate

DATE: 18/10/2020

COMPRESSIVE STRENGTH TEST

**Test Method and
Specification Reference :**

BS 3921:1985, BS 1881-116-1983, BS EN 1996-1-1, BS EN 772-1:2011, BS EN 771-1:2003, BS EN 772-7:1998, BS EN 772-3:1998.

PROJECT:	ACADEMIC RESEARCH - MSc				
CONTRACTOR:	N/A	CLIENT:	Nabbala moses Mumpembe		
SPECIMEN DETAILS:					
SPECIMEN DIMENSION:	210x135 x 60 (mm)	Test area (mm²)	3848.45		
STRUCTURAL MEMBER:	Clay bricks	SOURCE MATERIAL:	Clay from Mukono		
DATE TESTED:	19/08/2020	ADMIXTURE ADDED:	NONE	AGE:	N/A
LAB TECH: Emma. O					
Improved chemical composition unit from purified Mukono dark grey clay					
Specimen Label/Reference	Weight (Kg)	Density (Kg/m ³)	Maximum Load (KN)	Compressive Strength (MPa)	Mode Of Failure
1	-	-	9.8	2.55	Satisfactory / Unsatisfactory
2	-	-	8.4	2.18	Satisfactory / Unsatisfactory
3	-	-	9.5	2.47	Satisfactory / Unsatisfactory
4	-	-	9.4	2.44	Satisfactory / Unsatisfactory
5	-	-	8.0	2.08	Satisfactory / Unsatisfactory
FAILURE MODES					
<div style="display: flex; justify-content: space-around; align-items: center;"> <div style="text-align: center;"> <p>Unsatisfactory mode of failure</p>  </div> <div style="text-align: center;">  <p>Satisfactory mode of failure</p> </div> </div>					
MACHINE SPEC: CONTROLS, EN - WIZARD BASIC			COMPILED BY:  P. OCHIENG MATERIALS ENGINEER / LAB MANAGER		ENDORSED BY:  DR. L. MUNIWEZI HEAD OF DEPARTMENT, CBE
REMARKS:					
<ul style="list-style-type: none"> Brick density and compressive strength calculated with volumes and areas of Nominal dimensions. Bricks were found with no defects 					

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Test Certificate

DATE: 18/10/2020

COMPRESSIVE STRENGTH TEST

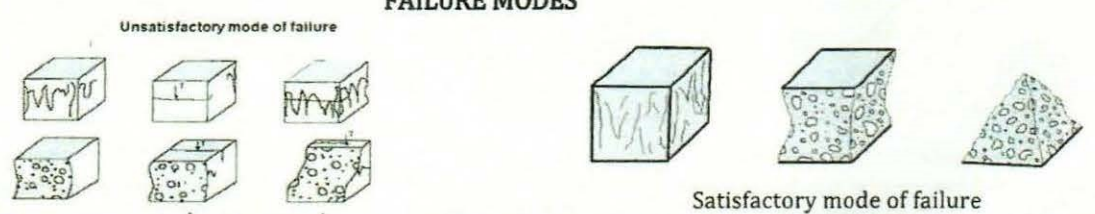
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PROJECT:	ACADEMIC RESEARCH - MSc		
CONTRACTOR:	N/A	CLIENT:	Nabbala moses Mumpembe
SPECIMEN DETAILS:			
SPECIMEN DIMENSION:	210x135 x 60 (mm)	Test area (mm²)	28.350
STRUCTURAL MEMBER:	Clay bricks	SOURCE MATERIAL:	Clay from Lira
DATE TESTED:	19/08/2020	ADMIXTURE ADDED:	NONE
		AGE:	N/A
		LAB TECH: Emma. O	

Artisan common clay brick of Lira

Specimen Label/Reference	Weight (Kg)	Density (Kg/m ³)	Maximum Load (KN)	Compressive Strength (MPa)	Mode Of Failure
1	3.4	1999	58.60	2.06	Satisfactory / Unsatisfactory
2	3.2	1882	29.50	1.04	Satisfactory / Unsatisfactory
3	3.0	1765	35.29	1.24	Satisfactory / Unsatisfactory
4	3.4	1999	38.28	1.35	Satisfactory / Unsatisfactory
5	3.2	1882	23.45	0.83	Satisfactory / Unsatisfactory

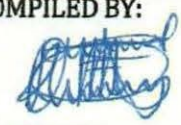
FAILURE MODES



MACHINE SPEC:
 CONTROLS, EN - WIZARD BASIC


REMARKS:

- Brick density and compressive strength calculated with volumes and areas of Nominal dimensions.
- Bricks were found with no defects

COMPILED BY:


P. OCHIENG
 MATERIALS ENGINEER /
 LAB MANAGER

ENDORSED BY:


 DR. L. MUHWEZI
 HEAD OF DEPARTMENT,
 CBE
 KYAMBOGO UNIVERSITY

Our Ref: 0199-CONC/SEPT-2020

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COMPRESSIVE STRENGTH TEST

**Test Method and
Specification Reference :**

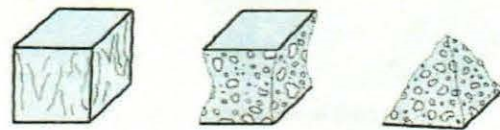
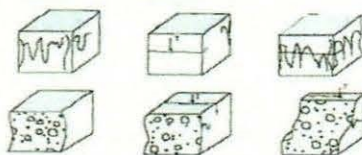
BS 3921:1985, BS 1881-116-1983, BS EN 1996-1-1, BS EN 772-1:2011, BS EN 771-1:2003, BS EN 772-7:1998, BS EN 772-3:1998.

PROJECT:	ACADEMIC RESEARCH - MSc		
CONTRACTOR:	N/A	CLIENT:	Nabbala moses Mumpembe
SPECIMEN DETAILS:			
SPECIMEN DIMENSION:	180x107 x 60 (mm)	Test area (mm²):	19260
STRUCTURAL MEMBER:	Clay bricks	SOURCE MATERIAL:	Clay from Lira
DATE TESTED:	19/08/2020	ADMIXTURE ADDED:	NONE
		AGE:	N/A
LAB TECH: Emma. O			
Improved mold bricks from Lira raw clay			

Specimen Label/Reference	Weight (Kg)	Density (Kg/m ³)	Maximum Load (KN)	Compressive Strength (MPa)	Mode Of Failure
1	2	1731	131	6.8	Satisfactory / Unsatisfactory
2	2.3	1990	93	4.8	Satisfactory / Unsatisfactory
3	2.3	1990	65.5	3.4	Satisfactory / Unsatisfactory
4	2.3	1990	95	4.9	Satisfactory / Unsatisfactory
5	2.3	1990	80	4.2	Satisfactory / Unsatisfactory

FAILURE MODES

Unsatisfactory mode of failure



Satisfactory mode of failure

<p>MACHINE SPEC: CONTROLS, EN - WIZARD BASIC</p> <p>REMARKS:</p> <ul style="list-style-type: none"> Brick density and compressive strength calculated with volumes and areas of Nominal dimensions. Bricks were found with no defects 	<p>COMPILED BY:</p> <p style="text-align: center;"></p> <p>P. OCHIENG MATERIALS ENGINEER / LAB MANAGER</p>	<p>ENDORSED BY:</p> <p style="text-align: center;"></p> <p>DR. L. MUHWEZI HEAD OF DEPARTMENT, CBE</p>
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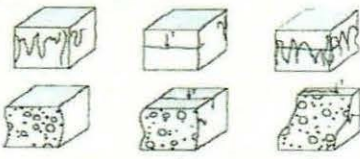



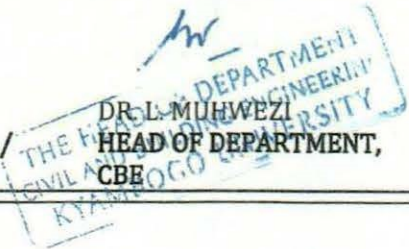
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EN 771-1:2003, BS EN 772-7:1998, BS EN 772-3:1998.

PROJECT:	ACADEMIC RESEARCH - MSc				
CONTRACTOR:	N/A	CLIENT:	Nabbala moses Mumpembe		
SPECIMEN DETAILS:					
SPECIMEN DIMENSION:	Ø 70x75 thick (mm)	Test area (mm²)	3848.45		
STRUCTURAL MEMBER:	Clay bricks	SOURCE MATERIAL:	Clay from Lira		
DATE TESTED:	19/08/2020	ADMIXTURE ADDED:	NONE	AGE:	N/A
LAB TECH: Emma. O					
Improved chemical composition units from purified Lira light grey clay					
Specimen Label/Reference	Weight (Kg)	Density (Kg/m ³)	Maximum Load (KN)	Compressive Strength (MPa)	Mode Of Failure
1	-	-	10.3	2.68	Satisfactory / Unsatisfactory
2	-	-	10.6	2.75	Satisfactory / Unsatisfactory
3	-	-	5.2	1.35	Satisfactory / Unsatisfactory
4	-	-	13.3	3.45	Satisfactory / Unsatisfactory
5	-	-	8.1	2.1	Satisfactory / Unsatisfactory
FAILURE MODES					
Unsatisfactory mode of failure					
					
Satisfactory mode of failure					
					
MACHINE SPEC: CONTROLS, EN - WIZARD BASIC			COMPILED BY:  P. OCHIENG MATERIALS ENGINEER / LAB MANAGER		ENDORSED BY:  DR. L. MUHWEZI HEAD OF DEPARTMENT, CBE
REMARKS:					
<ul style="list-style-type: none"> Brick density and compressive strength calculated with volumes and areas of Nominal dimensions. Bricks were found with no defects 					

APPENDIX III:

Calculations for Characteristic Strengths of Bricks

Characteristic Strength of Artisan Clay Brick from Lira

Item	Ultimate compressive strength(f)	f_m	$f-f_m$	$(f-f_m)^2$
1	2.06	1.304	0.756	0.571536
2	1.04	1.304	-0.264	0.069696
3	1.24	1.304	-0.064	0.004096
4	1.35	1.304	0.046	0.002116
5	0.83	1.304	-0.474	0.224676
	6.52			0.87212

$$\text{Mean} = \sum f/n = 6.52/5 = 1.304$$

$$\text{Standard deviation } (\sigma) = \sqrt{(\sum (f-f_m)^2/n)} = \sqrt{0.87212/5} = 0.42$$

$$\text{X-teristic strength} = f_m - 1.6\sigma = \{1.304 - (1.6 \times 0.42)\} = 0.63 \text{N/mm}^2$$

$$\text{Characteristic strength} = 0.63 \text{N/mm}^2$$

Characteristic Strength of Relative Uniform Applied Force Made Brick from Raw Clay Lira

Item	Ultimate compressive strength(f)	f_m	$f-f_m$	$(f-f_m)^2$
1	6.8 (Not considered)			
2	4.8	4.3	0.5	0.25
3	3.4	4.3	-0.9	0.81
4	4.9	4.3	0.7	0.49
5	4.2	4.3	-0.1	0.01
	17.3			1.56

$$\text{Mean} = \sum f/n = 17.3/4 = 4.3$$

Standard deviation (σ) = $\sqrt{(\sum (f-f_m)^2/n)} = \sqrt{(1.56/4)}=0.62$

X-teristic strength= $f_m-1.6\sigma=4.3-1.6\times 0.62=3.3$

Characteristic strength=3.3N/mm²

Characteristic Strength of Artisan Clay Brick from Mukono

	Ultimate compressive strength(f)	f_m	$f-f_m$	$(f-f_m)^2$
1	0.67	1.614	-0.944	0.891136
2	1.59	1.614	-0.024	0.000576
3	0.88	1.614	-0.734	0.538756
4	2.27	1.614	0.656	0.430336
5	2.66	1.614	1.046	1.094116
	8.07			2.95492

Mean= $\sum f/n=8.07/5=1.614$

Standard deviation (σ) = $\sqrt{(\sum (f-f_m)^2/n)}=\sqrt{(2.95492/5)}=0.769$

X-teristics strength= $f_m-1.6(\sigma) =1.614-1.6\times 0.769=0.38\text{N/mm}^2$

Characteristic Strength of Relative Uniform Applied Force Made Brick from Raw Clay Mukono

Item	Ultimate compressive strength(f)	f_m	$f-f_m$	$(f-f_m)^2$
1	0.82(Not considered)			
2	7.66	5.4	2.2	4.84
3	5.05	5.4	-0.35	0.12
4	3.36	5.4	-2.04	4.16
5	1.05(Not considered)			

Mean= $\sum f/n=16.07/3=5.4$

Standard deviation (σ) = $\sqrt{(\sum (f-f_m)^2/n)} = \sqrt{(9.12/3)} = 1.74$

X-teristic strength= $f_m-1.6\sigma=5.4-1.6\times 1.74=2.62$

Characteristic strength=2.62

Characteristic Strength of Clay Unit from Purified Light Grey Clay of Lira

N	Ultimate compressive strength(f)	f_m	$f-f_m$	$(f-f_m)^2$
1	2.68	2.745	-0.065	0.004225
2	2.75	2.745	0.005	2.5E-05
3		2.745		
4	3.45	2.745	0.705	0.497025
5	2.1	2.745	-0.645	0.416025
	10.98			0.9173

$$\text{Mean } (f_m) = \sum f/n = 10.98/4 = 2.745$$

$$\text{Standard deviation } (\sigma) = \sqrt{(\sum (f-f_m)^2/n)} = \sqrt{(0.9173/4)} = 0.48$$

$$\text{X-teristic strength} = F_m - 1.6\sigma = 2.745 - 1.6 \times 0.48 = 2.745 - 0.768 = 1.977 \text{ N/mm}^2$$

Characteristic Strength of Clay Unit from Purified Brown Clay Mukono

Item	Ultimate compressive strength(f)	f_m	$f-f_m$	$(f-f_m)^2$
1	4.7	7.65	-2.95	8.7025
2	7.56	7.65	-0.09	0.0081
3	9.33	7.65	1.68	2.8224
4	8.26	7.65	0.61	0.3721
5	8.4	7.65	0.75	0.5625
	38.25			12.4676

$$\text{Mean } (f_m) = \sum f/n = 38.25/5 = 7.65$$

$$\text{Standard deviation } (\sigma) = \sqrt{(\sum (f-f_m)^2/n)} = \sqrt{(12.4676/5)} = 1.58$$

$$\text{X-teristic strength of clay unit from from purified brown clay Mukono} = f_m - 1.6 \sigma$$

$$= 7.65 - 1.6 \times 1.58 = 5.122 \text{ N/mm}^2$$

APPENDIX IV

Water absorption test results and calculations

Water Absorption Test Results for Artisan Bricks from Mukono

SN	A Size of brick			Weight of dry brick(g)	Average weight of the dry brick(M1)	Weight of wet brick after 24 hr immersion	Average weight of wet brick M2	Water absorbed by the brick (%)
	L(mm)	B(mm)	H(mm)					
1	195	100	104	3607		3761.9		
2	192	99	95	3208		3748.6		
3	194	100	95	3306.9	3337.1	3606.4	3758.76	12.64
4	187	105	99	3273.9		3555.4		
5	189	100	99	3289.7		4121.5		
				16685.5		18793.8		

$$(M2-M1)/M1 = (3758.76-3337.1)/3337.1$$

$$= 0.1264 \times 100$$

Water absorbed by the brick = 12.64%

$$\text{First class condition } 1/6 \text{ of dry weight} = 1/6 \times 3337.1$$

$$= 556.18\text{g}$$

$$556.18/3337.1$$

$$= 0.1666$$

$$=0.1666 \times 100$$

$$=16.66\%$$

Water absorbed by the artisan clay brick Mukono is 12.64% less than (16.66%),
hence class one

**Water Absorption Test Results for Clay Units from Purified Light Grey Clay
(improved chemical composition), Mukono**

SN	Size of clay unit	Weight of dry clay unit (grms)	Average weight of dry clay unit (M1) grms	Weight of wet clay unit (grms)	Average weight of wet clay unit (grms) (M2)
1	Ø 70 mm	250.4		279.8	
2	Ø 70 mm	251.4		286	
3	Ø 70 mm	111.4	223.18	127.1	252.06
4	Ø 70 mm	250.6		280.1	
5	Ø 70 mm	252.1		287.3	

$$(M2-M1)/M1 = 253.06-223.18/223.18$$

$$=29.88/223.18=0.134$$

$$\text{Water absorbed} = 0.134 \times 100 = 13.4\%$$

$$\text{First class condition } 1/6 \text{ of dry weight} = 223.18/6 = 37.2$$

$$=37.2/223.18 \times 100$$

$$=16.6\%$$

Water absorbed 13.4% less than 16.6% hence first-class brick

**Water Absorption Test Results for Clay Units from Purified Brown Clay
(improved chemical composition), Mukono**

SN	Size of clay unit	Weight of dry clay unit (grms)	Average weight of dry clay unit(M1) grms	Weight of wet clay unit (grms)	Average weight of wet clay unit (grms) (M2)
1	Ø 70 mm	285.7		313.9	
2	Ø 70 mm	275.2		325.2	
3	Ø 70 mm	275.6	281.72	326.2	318.92
4	Ø 70 mm	285.9		314.1	
5	Ø 70 mm	286.2		315.2	

$$M2-M1)/M1 = 318.92-281.72/281.72$$

$$=37.2/281.72=0.132$$

$$\text{Water absorbed} = 0.132 \times 100 = 13.2\%$$

$$\text{First class condition } 1/6 \text{ of dry weight} = 281.72/6 = 46.95$$

$$= 46.95/281.72 \times 100$$

$$= 16.6\%$$

Water absorbed 13.2% less than 16.6% hence first-class brick

**Water Absorption Test Results for Clay Units from Purified Dark Grey Clay
(improved chemical composition), Mukono**

SN	Size of clay unit	Weight of dry clay unit (grms)	Average weight of dry clay unit(M1) grms	Weight of wet clay unit (grms) M1	Average weight of wet clay unit (grms) (M2)
1	Ø 70 mm	228.89		292.9	
2	Ø 70 mm	229.7		294	
3	Ø 70 mm	229.4		293.7	
4	Ø 70 mm	228.99	229.37	293.9	293.76
5	Ø 70 mm	229.88		294.3	

$$(M2-M1)/M1 = 293.76-229.37/229.37$$

$$=64.39/229.37=0.281$$

$$\text{Water absorbed} = 0.289 \times 100 = 28.1\%$$

$$\text{First class condition } 1/6 \text{ of dry weight} = 229.37/6 = 38.23$$

$$= 38.23/229.37 \times 100$$

$$= 16.6\%$$

Water absorbed 28.1% greater than 16.6% hence less compared to the artisan brick

$$\text{Second class conditions of } 1/4 \text{ of the dry weight } 229.37 = 57.34\text{g}$$

$$=57.34/229.37 \times 100$$

$$=25.03\%$$

Water absorbed 28.1% greater than 25.035% the brick cannot be used in construction. Purification of grey and brown clays improves products made out of them to first class.

Water Absorption Test Results for Artisan Bricks from Lira

SN	L(mm)	B(mm)	H(mm)	Weight of dry brick	Average weight of dry brick(M1)	Weight of wet brick(M2)	Average weight of wet brick(M2)
1	205	135	66	3239.9		3720.2	
2	205	135	60	3039.2		3515.2	
3	215	141	68	3555.4	3217.44	3535.4	3754.3
4	211	135	61	3092.7		4023.9	
5	210	139	62	3160		3976.8	
				16087.2		18771.5	

$$(M2-M1)/M1 = (3754.3-3217.4)/3217.4$$

$$= 0.1669 \times 100$$

$$\text{Water absorbed by the brick} = 16.69\%$$

$$\text{First class condition } 1/6 \text{ of dry weight} = 1/6 \times 3217.4$$

$$= 536.23\text{g}$$

$$536.23/3217.4 = 0.1667$$

100

$$=0.1667 \times 100$$

$$=16.67\%$$

Water absorbed by the brick is 16.69 greater than 1/6(16.67) %, hence artisan brick from Lira not classified as class one.

Comparing it with the class two which is $\frac{1}{4}$ of its dry weight i.e.

$$\frac{1}{4} \times 3217.4 = 804.35 \text{g}$$

$$\frac{804.35}{3217.4} = 0.25$$

$$= .25 \times 100$$

$$= 25\%$$

Water absorbed by the brick is 16.69% less than (25%, hence the artisan brick from Lira is classified as class two.

**Water Absorption Test Results for Clay Units from Purified Light Grey Clay
(improved chemical composition), Lira**

SN	Size of clay unit	Weight of dry clay unit (grms)	Average weight of dry clay unit(M1) grms	Weight of wet clay unit (grms)	Average weight of wet clay unit (grms) (M2)
1	Ø 70 mm	318		345.5	
2	Ø 70 mm	298.5		404.1	
3	Ø 70 mm	347.7	334.4	371.3	388.6
4	Ø 70 mm	333.7		387.6	
5	Ø 70 mm	374.2		432.3	

$$(M2-M1)/M1 = 388.6-334.4/334.4=54.2g$$

$$=54.2/334.4=0.162$$

$$\text{Water absorbed} = 0.162 \times 100 = 16.2\%$$

$$\text{First class condition } 1/6 \text{ of dry weight} = 334.4/6 = 55.7$$

$$= 55.7/334.4 \times 100$$

$$= 16.66\%$$

Water absorbed 16.2% less than 16.66% hence first-class and shows an improvement compared from the artisan brick.

**Water Absorption Test Results for Clay Units from Purified Brown Clay
(improved chemical composition), Lira**

SN	Size of clay unit	Weight of dry clay unit (grms)	Average weight of dry clay unit(M1) grms	Weight of wet clay unit (grms)	Average weight of wet clay unit (grms) (M2)
1	Ø 70 mm	379.9		398.3	
2	Ø 70 mm	391.4		448	
3	Ø 70 mm	363.9	368.34	410.7	421.54
4	Ø 70 mm	348.8		434.4	
5	Ø 70 mm	357.7		416.3	

$$(M2-M1)/M1 = 421.54-368.34/368.34$$

$$=53.2/368.34=0.144$$

$$\text{Water absorbed} = 0.144 \times 100$$

$$=14.4\%$$

$$\text{First class condition } 1/6 \text{ of dry weight} = 368.34/6 = 61.39$$

$$=61.39/368.34 \times 100$$

$$=16.6\%$$

Water absorbed 14.4% less than 16.6% hence first-class brick an improvement compared from the artisan brick.

**Water Absorption Test Results for Clay Units from Purified Brown Clay
(improved chemical composition), Lira**

SN	Size of clay unit	Weight of dry clay unit (grms)	Average weight of dry clay unit(M1) grms	Weight of wet clay unit (grms)	Average weight of wet clay unit (grms) (M2)
1	Ø 70 mm	344.2		404.7	
2	Ø 70 mm	369.3		436.5	
3	Ø 70 mm	327.9	348.12	382.1	409.58
4	Ø 70 mm	329.1		386.4	
5	Ø 70 mm	370.1		438.2	

$$(M2-M1)/M1 = 409.58-348.12/348.12$$

$$=61.46/348.12=0.177$$

$$\text{Water absorbed} = 0.177 \times 100 = 17.7\%$$

$$\text{First class condition } 1/6 \text{ of dry weight} = 348.12/6 = 58.02$$

$$= 58.02/348.12 \times 100$$

$$= 16.6\%$$

Water absorbed 17.7 greater than 16.6% hence not first class

$$\text{Second class condition } 1/4 \text{ of dry weight} = 348.12/4 = 87.93$$

$$= 87.93/348.12 \times 100$$

=25.25%

Water absorbed 17.7 less than 25.5% hence class two no improvement as compared to the artisan brick.

APPENDIX V

Questions for artisans during interviews

1. What is the name of a place where you are practicing making of bricks?
2. What is your name?
3. How long have you been in the brick making field?
4. How do you process the clay from start of business to time of selling your finished bricks to your customers?
5. How do you know that the soil you are dealing with is clay?
6. How do you ensure that the bricks you make are of the same dimensions?

N.B Descriptions of each code i.e., mining, molding, tempering, burning, clay identification, brick cooling and brick seasoning were written on separate papers for each artisan.