



Assessment of Artisan Clay Bricks for Structural Strength, Chemical Stability and Durability

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Abstract: The artisan clay bricks in Uganda are characterised with low strength, erosion, tiny cracks, lime pop out, warping, efflorescence occurrence 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 SiO₂, Al₂O₃, Fe₂O₃ & 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 mineral requirements for manufacturing bricks was not satisfactory, for artisan bricks, they had very low characteristic strengths of 0.63N/mm² for Lira and 0.38N/mm² for Mukono. 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 (improved chemical composition bricks) and 3.3 (improved molded bricks) for Lira, 5.12 (improved chemical composition bricks) and 2.62N/mm² (improved molded bricks) for Mukono, slight efflorescence and low water absorption. Studies therefore recommend that the artisan do include both refining processing and constant force kneaded clay pressing in the manufacturing process.

Keywords: Brick for Structural Strength, Chemical Stability, Durability

1. 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 [1] known building materials dating back to 7000BC. Clay bricks have been widely preferred as building material because of their high compressive strength, durability, fire and weathering resistance, thermal and sound insulation [7]. Basic principles of manufacturing bricks are fairly the same but individual manufacturers do tailor their manufacturing process to fit their particular clay raw materials. Process tailoring to fit particular clay causes brick makers/manufacturers to make mistakes leading to poor quality products which are characterised of Lime pop out, blistering (tiny holes), cracks, warping, softness or low strength under burning, efflorescence, brick erosion, high water absorption etc.

Bricks in first class should not absorb more than one sixth of

its dry weight, second class should not absorb more than a quarter of its dry weight [15]. For brick manufacturing, clay must possess some specific properties and characteristics. Clay is one of the most abundant natural materials on earth [5]. 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 [5]. 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 [7]. 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

[11]. 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 [11].

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 bricks in Uganda are largely characterized by defects like lime pop out, warping, cracks, high water absorption, erosion, blistering, low compressive strength, occurrences of efflorescence on built walls which is assign of poor-quality brick. The characterized defects of the artisan manufactured clay brick in Uganda leads to low strength of walling units, dump rooms, poor appearance of walls, frequent repainting of walls, lack of trust for structural specification during design process, high projects cost due to high waste generation during handling and construction, less durability of structures and variations in quality of brick products. The possible causes of poor-quality bricks could be, the poor chemical composition of clay, presence of coarse materials in the clay and poor methods of manufacturing. There is need therefore to improve the quality of bricks by refining raw clay and applying improved manufacturing methods.



Figure 1. Erosion.



Figure 2. Cracks and breakage.



Figure 3. Efflorescence.

1.3. Objective of the Study

1.3.1. Main Objective

To assess causes of poor structural strength, chemical instability and low durability of artisan manufactured clay bricks in Uganda and recommend measures for improvement.

1.3.2. Specific Objectives

The specific objectives of the study are:

1. Establish the present manufacturing process used by the artisans in the manufacture of local clay bricks;
2. To determine the chemical percentage (Al_2O_3 , SiO_2 , Fe_2O_3 and CaO) compositions of clay locally used by the artisans, in manufacturing bricks in Uganda [17, 18];
3. To improve on the percentage chemical (Al_2O_3 , SiO_2 , Fe_2O_3 and CaO) composition ratios as related to the ideal composition for quality;
4. Recommend a new method of manufacturing improved artisan clay brick to meet specific characteristics properties of producing durable, chemically stable and strong burnt clay brick.

1.4. Research Questions

The research was aimed at addressing the following research questions:

1. What methods do artisans follow during manufacturing of local clay bricks in Uganda?
2. 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?
3. 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?
4. What can be done to improve the brick manufacturing process to produce the chemically stable, durable, strong and reliable artisan clay brick for construction?

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 [11]. 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. Geographical

The research was conducted in Uganda. Representative clay samples were obtained from the artisan manufacturing sites in the districts of Mukono, Lira and Kamuli.

1.7.2. Time

The research was conducted from December 2018 to October 2020.

1.7.3. Content Scope

The research was limited to manufacturing of brick from raw and purified clay, tests for water absorption, compressive crushing 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.

1.8. Conceptual Framework

The strength, chemical stability and durability of clay bricks depends on the chemical composition of clay and on the manufacturing process which includes mixing, proportionating of clay constituents, drying and brick firing [14]. The independent variables which are indicators of variables are the manufacturing processing quality for classifications of bricks are compressive strength, water absorption and efflorescence. The dependant used by the artisan and the chemical structure of the clay used.

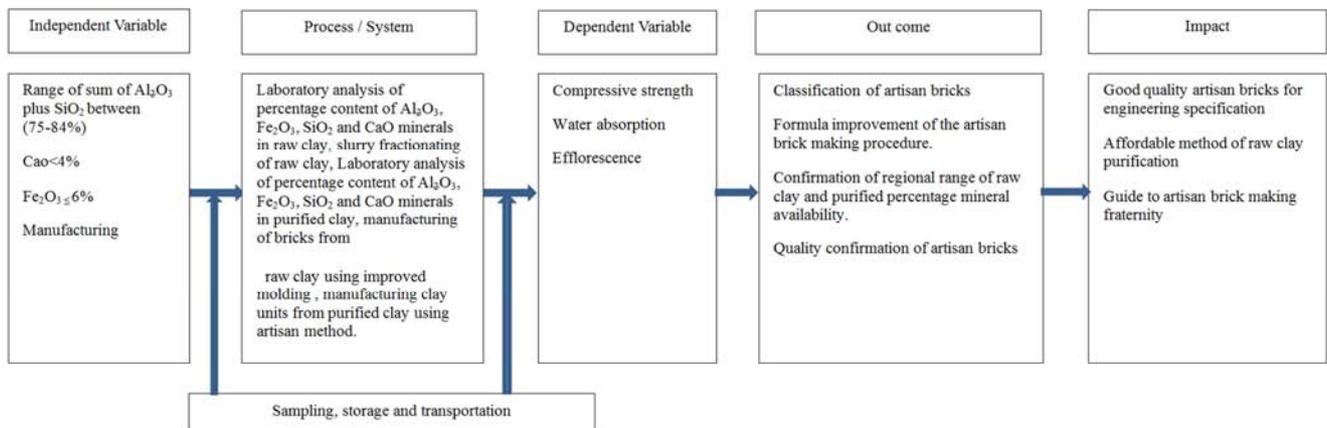


Figure 4. Conceptual frame work.

2. Methodology

2.1. 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 manufacturing bricks.

It further describes the methods of determining the compressive crushing strengths, water absorption,

efflorescence ability and classification of bricks.

2.1.1. Study Area

Districts in Uganda were divided into four major regions i.e. northern, eastern, western and central. Random sampling was carried out. Results were that Mukono was picked for central, Lira for northern, Kamuli for eastern and Kisoro for western. 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.

2.1.2. 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 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.

Three representative 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 is taken as 5 pieces. 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. From the storage the natural wet clay was given two months to dry. After drying, lamped 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.

2.2. Artisan Brick Manufacturing Process in Uganda

The following are the stages in which the Ugandan brick artisans do manufacture the clay bricks:

Visual identification of clay deposits in the area of operation

Mining of clay from clay deposits areas and heaping the mined clay.

Tempering of clay

Molding of brick units

Drying of molded brick

Burning of bricks and cooling

2.2.1. 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.

2.2.2. 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.

2.2.3. 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 [13]. 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.

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



Figure 5. Artisan Method of Brick Molding.

2.2.5. 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 6. Field Kiln Burning of Bricks and Cooling.

After stacking the green bricks in a field kiln as shown in Figure 6, the fuel in form of firewood or agriculture waste e.g., coffee husks, rice husks, wood dust 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 Kampala are between 2.1 to 3.0 meters in width and 3.5 to 6.0 metres 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 opening 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.

2.3. 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.

2.3.1. 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.

2.3.2. Data Analysis

The test results obtained were analysed using Microsoft excel.

2.4. 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: -

1. 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 .
2. Determination of 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.

3. Determine the purity level /response of clay from different regions of Uganda.

2.5. 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 existence 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.

2.5.1. Objective

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 [10, 17]. These constituents must be in certain proportions for quality brick making [10, 13]. 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.

2.5.2. Significance

The importance of carrying out the analysis for natural and purified clay of the percentage existence 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, chemically stable and durable.

2.5.3. Apparatus

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

2.5.4. Procedure

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

2.5.5. 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.

2.6. Clay Purification

The clay purification [2, 3] 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.

2.6.1. Significance

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.

2.6.2. Test Apparatus

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

2.6.3. Test Procedure

1. Three transparent buckets labelled A, B and C were used in each test.
2. 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.
3. Water was then topped on the natural clay to approximately filling to 90% of each bucket by volume.
4. 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.
5. A third transparent bucket A in each experiment was covered on top with a closely weaved cloth and secured firm with rubber band.
6. 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).
7. 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.

2.6.4. Observations

1. The clay that was in bucket C, was left settling and observed to have developed into layers.
2. The top most layer was clear water with floating organic materials
3. The second layer from top was smooth on touching and sticky
4. The third layer from top was smooth but not sticky on touching
5. The fourth layer from the top was coarse on touching and rough.
6. 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.
7. 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 stop because the coarse materials are not found to be good.

8. 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 [4, 8].
9. The yield of the sticky layer was seen more in brown clay, seconded by light grey clay and was list in dark grey clay.

2.7. Compressive Strength Test

2.7.1. Objective

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.

2.7.2. Significance

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

2.7.3. Sample Preparation

The artisan clay brick samples were obtained from parent source and were ready for testing. The clay units from purified clay were moulded using artisan moulding style; bricks from raw clay moulded using improved mold shown in Figure 7, dried, and baked before tested.



Figure 7. Improved Metal mold.

2.7.4. Apparatus

Hydraulic compressive testing machine
Steel measuring tape
Calculator
Note book
Pen

2.7.5. Procedure

1. All the prepared material was assembled in the laboratory.
2. The dimensions of each brick in contact with the bearing surface were taken for each brick.
3. 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.
4. All contact surfaces and crushing forces for each brick were recorded in a standard form to allow calculation of crushing force for each brick.
5. Average crushing force for each type from different regions, manufactured bricks from purified & raw clay and artisan was got for comparison.

2.7.6. Reporting

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

2.8. Absorption Tests

2.8.1. Objective

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).

2.8.2. Significance

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.

2.8.3. Apparatus

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

2.8.4. Procedure

1. Five bricks from artisan sites, five improved molded bricks and improved chemical composition clay units

were selected from Mukono and Lira.

2. Each dry baked brick was cleaned of loose sand /clay and were marked 1,2,3,4 and 5.
3. Each cleaned dry brick was weighed and the dry weight recorded as M1.
4. 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.
5. Average weight for the dry and that of the wet were calculated.
6. From the averages the dry values and the wet values of the bricks, absorption was calculated as:

$$\text{Absorption} = \frac{\{(M_2 - M_1)\} \times 100}{M_1} [12, 16]$$

2.8.5. Reporting of Results

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

2.9. Efflorescence

2.9.1. 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.

2.9.2. 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.

2.9.3. Apparatus

Transparent buckets
 Alarm clock
 Procedure

1. Five bricks were selected from each sample and the bricks were labelled bearing the name of their origin.
2. All the bricks were totally immersed in clean water for 24 hours
3. After 24 hours all were removed and placed under shade where there was enough air circulation.
4. After two weeks the brick surfaces were observed, to monitor salt migration that had occurred on their surfaces.

2.9.4. Reporting

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

3. Test Results from Experiments

Table 1. Results of Percentage content of Al₂O₃, Fe₂O₃, SiO₂ and CaO in Natural and Purified state.

Results of Percentage Content of Al ₂ O ₃ , Fe ₂ O ₃ , SiO ₂ and CaO in Natural State							
Sample Name	Al ₂ O ₃ (ppm)	Al ₂ O ₃ %	Fe ₂ O ₃ (ppm)	Fe ₂ O ₃ (%)	CaO (ppm)	CaO (%)	SiO ₂ (%)
Lira Brown Clay	17194.14	1.7	14956.15	1.5	13168.99	1.3	85.0
Lira Light Grey Clay	22280.59	2.2	11194.83	1.1	5736.69	0.6	85.0
Lira Dark Grey Clay	3008.80	0.3	5379.09	0.5	894.56	0.09	92.5
Mukono Brown Clay	9214.02	0.9	18326.61	1.8	2088.20	0.2	91.2
Mukono Light Grey Clay	11497.95	1.1	15502.82	1.6	4801.15	0.5	86.1
Mukono Dark Grey Clay	6999.93	0.7	5799.11	0.6	18546.34	1.9	88.8
Kamuli Brown Clay	12686.92	1.2	1.2	0.9	7466.67	0.7	88.2
Kamuli Light Grey Clay	8191.01	0.8	2759.13	0.3	8726.62	0.9	68.4
Kamuli Dark Grey Clay	6086.30	0.6	3681.57	0.4	1002.77	0.1	98.7

Results of Percentage Content of Al ₂ O ₃ , Fe ₂ O ₃ , SiO ₂ and CaO in Purified Clay				
Sample Name	Al ₂ O ₃ %	Fe ₂ O 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 2. Compressive Test results for bricks from Lira.

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)
1	210x135	3.4	28,350	58.6	2.06
3	210x135	3.2	28,350	29.5	1.04
5	210x135	3	28,350	35.29	1.24
6	210x135	3.4	28,350	38.28	1.35
8	210x135	3.2	28,350	23.49	0.83

Characteristic strength of artisan clay brick from Lira is 0.63N/mm² from calculations

Compressive Tests Results for Improved Moldings Brick from Raw Clay Lira					
Item	Size of brick(mm)	Weight of the brick(kg)	Area of brick (mm ²)	Compressive crushing force read x1000N	Ultimate 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	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/mm² from calculations

Compressive Tests Results for Improved Chemical Composition Artisan Unit from Purified Lira Light Grey Clay					
Item	Size of clay unit	Area of clay	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	
3	Ø 70mm&75mm thick	3848.45	5.2	1.359 (not considered)	2.75
4	Ø 70mm&75mm thick	3848.45	13.3	3.45	
5	Ø 70mm&75mm thick	3848.45	8.1	2.1	

Characteristic strength of improved chemical composition artisan unit from purified Lira light grey clay is 2.0N/mm² from calculations

Table 3. Compressive Test Results for bricks from Mukono

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)
1	200x110	3.8	22,000	14.7	0.67
2	200x110	3.4	22,000	35	1.59

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)
3	200x110	3.1	22,000	19.4	0.88
4	200x110	2.8	22,000	50	2.27
5	200x110	3.8	22,000	58.9	2.68

Characteristic strength of Mukono artisan clay brick is 0.38N/mm²

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)
1	180x107	1.9	19260	15.7	0.82
2	180x107	2	19260	147.6	7.66
3	180x107	2	19260	97.4	5.05
4	180x107	1.8	19260	64.9	3.36
5	180x107	2	19260	20.2	1.05

Characteristic strength of improved molding brick from raw clay Mukono is 2.62N/mm² from calculations

Compressive Tests Results for Improved Chemical Composition Artisan Clay Unit from Purified Mukono Brown Clay					
Item	Size of clay unit	Area of clay unit	Compressive crushing force read x1000N	Ultimate compressive strength (N/mm ²)	Average compressive strength (N/mm ²)
1	Ø 70mm&75mm thick	3848.45	18.2	4.70	
2	Ø 70mm&75mm thick	3848.45	29.1	7.56	7.65
3	Ø 70mm&75mm thick	3848.45	35.9	9.33	
4	Ø 70mm&75mm thick	3848.45	31.8	8.26	
5	Ø 70mm&75mm thick	3848.45	32.4	8.4	

Characteristic strength of improved chemical composition artisan clay unit from Purified Mukono Brown Clay is 5.12 N/mm² from calculations

Table 4. Water Absorption Test Results for Bricks from Lira.

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	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	

Water Absorption Test Results for improved chemical composition unit from Purified Lira Light Grey Clay					
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	

Table 5. Efflorescence Test Results on Artisan, Improved chemical composition artisan and Improved Mould Bricks of Mukono and 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 [9, 13, 16]
1	Mukono artisan brick	20,000	4000	20%	Moderate
2	Lira artisan brick	29400	4500	15.30%	Moderate
3	Improved chemical artisan brick Mukono	3848.5	225	6%	Slight
4	Improved chemical artisan brick Lira	3848.5	2 475	12.3%	Moderate
5	Improved mould brick Mukono	19260	2899	15%	Moderate
6	Improved mould brick Lira	19270	2696.4	14%	Moderate

4. Discussions and Conclusions

4.1. Discussions

Table 6. Percentage sum of Aluminate and Silicon dioxide in Natural Sample.

Sample name	Al ₂ O ₃ (%)	SiO ₂ (%)	Percentage sum of aluminate& silicon dioxide	Acceptable range (75-84%) [10]	Remarks
Lira Brown Clay	1.7	90.0	91.7%	75-84%	Above Max.
Lira Light Grey Clay	2.2	85.0	87.2%	75-84%	Above Max.
Lira Dark Grey Clay	0.3	92.5	92.8%	75-84%	Above Max.
Mukono Brown Clay	0.9	91.2	92.1%	75-84%	Above Max.
Mukono light grey Clay	1.1	86.1	87.2%	75-84%	Above Max.
Mukono dark grey Clay	0.7	88.8	89.5%	75-84%	Above Max.
Kamuli Brown Clay	1.2	88.2	89.4%	75-84%	Above Max.
Kamuli light grey Clay	0.8	68.4	69.2%	75-84%	Below minimum
Kamuli dark grey Clay	0.6	98.7	99.3%	75-84%	Above Max.

The results in this table all indicates that the available clay used by the artisan in Uganda was not good and it requires refining before is used for brick making.

Table 7. 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%) [10]	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)

The results in this table indicates that the refining of the clay by use of slurry fractionation method improves the clay to better manufacturing chemical composition

Table 8. Comparison of Percentage Content of Al₂O₃, Fe₂O₃ SiO₂ and CaO in Natural and Purified State of Clays of Lira and Mukono.

Sample Name	Chemical Name	% Composition in natural state	% Composition after purification	% Acceptable range for ideal industrial manufacture of clay bricks [6, 10, 13]
Lira Light grey clay	Al ₂ O ₃	2.2	2.63	20-30
	Fe ₂ O ₃	1.1	1.66	4-6
	SiO ₂	85	80.4	55-70
	CaO	0.6	0.04	≤4
Lira dark grey clay	Al ₂ O ₃	0.3	2.02	20-30
	Fe ₂ O ₃	0.5	1.41	4-6
	SiO ₂	92.5	95.98	55-70
	CaO	0.09	0.04	≤4
Lira brown clay	Al ₂ O ₃	1.7	2.95	20-30
	Fe ₂ O ₃	1.5	2.55	4-6
	SiO ₂	90	76.7	55-70
	CaO	1.3	0.1	≤4
Mukono Light grey clay	Al ₂ O ₃	1.1	1.5	20-30
	Fe ₂ O ₃	1.6	1.73	4-6
	SiO ₂	86.1	79.4	55-70
	CaO	0.5	0.06	≤4
Mukono dark grey clay	Al ₂ O ₃	0.7	1.99	20-30
	Fe ₂ O ₃	0.6	2.04	4-6
	SiO ₂	88.8	83.7	55-70
	CaO	1.9	0.01	≤4
Mukono brown clay	Al ₂ O ₃	0.9	2.42	20-30
	Fe ₂ O ₃	1.8	3.73	4-6
	SiO ₂	91.2	89.3	55-70
	CaO	0.2	0.09	≤4

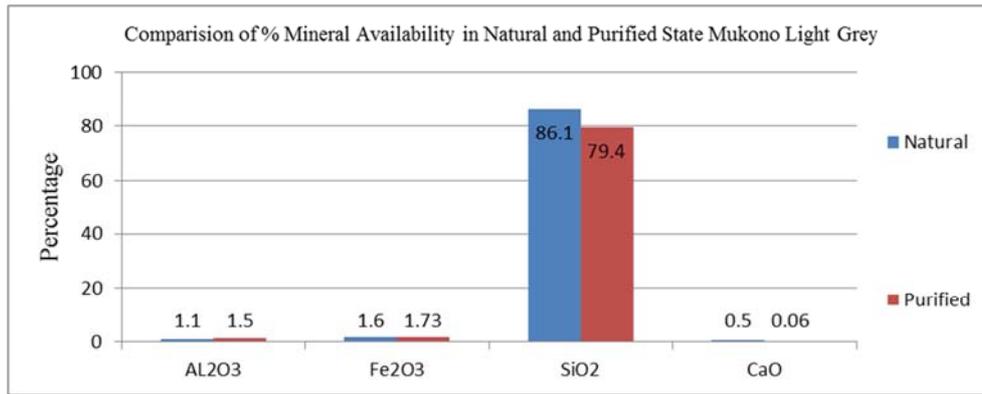


Figure 8. Comparison of Mineral Availability in Natural and Purified State Mukono Light grey.

When purification was applied on both lira and Mukono clays, there was increase in Aluminate and Iron three oxide and decrease in silicon dioxide and calcium oxide as compared raw clay. This kind of analogy was good because comparing with the raw clay mineral structure, the refining shifted the clay structure positively. Silicon dioxide is responsible for strength, hardness, resistance to shrinkage, shape of the brick and for durability is required in 55-70% for industrial ceramic manufacturing [10]. Mukono light grey was purified, silicon reduced from 86.6% to 79.4%, (unbonded) silicon was reduced in the raw clay by 7.2% hence increase in strength, hardness, resistance to shrinkage and durability. Aluminate is responsible for plastic character required in 20-30% [10, 13] increased from 1.1% to 1.5%, increase by 0.4% hence plasticity nature of the clay structure

increased.

CaO is a flux agent responsible for lowering down the softening temperature of the silica and quicker hardening of brick, is required in the amount of maximum of 4% [13]. Reduction in the CaO from 0.5 to 0.06% is positive because much of CaO causes excessive softening which imparts lower strength. Disassociation of CaO in the solution during fractionation is an indication of reduction in efflorescence effects of the resulting product as too much of CaO would cause hydration that result in easy disintegration of the brick [13]. Iron three oxide is responsible for imparting color to the brick and is required in the range of 4-6% [13]. Increase on Iron three oxide from 1.6 to 1.73% is positive and an indication of increasing the quality of color of the resulting product after purification of raw clay.

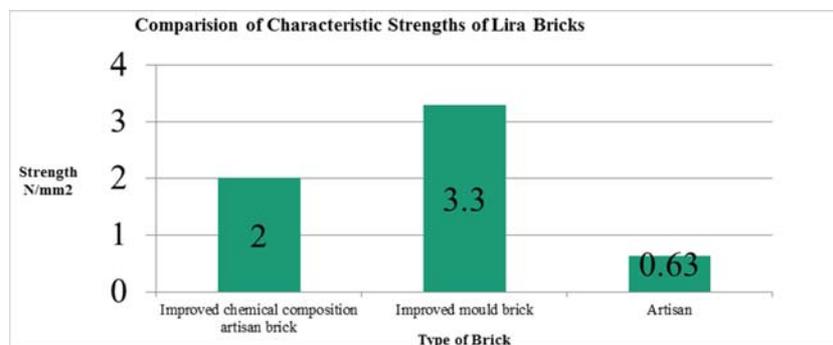


Figure 9. Comparison of characteristic strengths of Lira bricks.

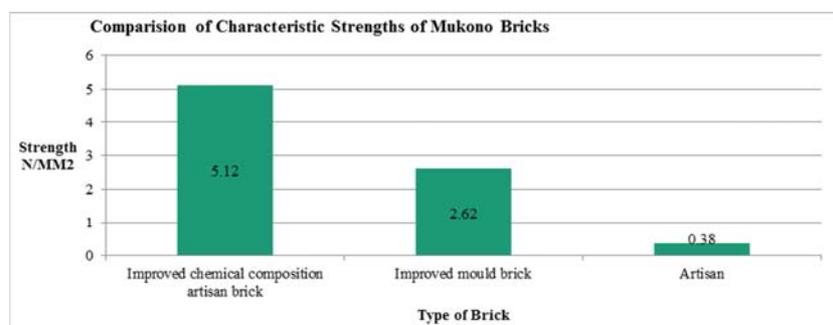


Figure 10. Comparison of characteristic strengths of Mukono bricks.

Characteristic strength of the Mukono artisan brick improved from 0.38 N/mm² to 2.62 N/mm² using improved

mold then from 0.38 N/mm² to 5.12 N/mm² using improved chemical composition and artisan molding. The same

operations were done on Lira clay and improvement was from 0.63 N/mm² to 3.3 N/mm² using improved mold then from 0.63 N/mm² to 2.0N/mm² using improved chemical composition and artisan molding. Both Lira and Mukono

bricks show that the method of purifying clay and use improved molding of bricks increases the characteristic values of the artisan brick.

Table 9. Water absorption for classification of bricks.

Artisan clay brick Lira		Improved chemical composition Artisan clay unit from light grey clay Lira	
Average weight of dry brick (gm) M1	Average weight of wet brick(gm) M2	Average weight of dry brick(gm) M1	Average weight of wet brick (gm) M2
3217.44	3754.3	333.4	388.6
$(M2-M1)/M=(3754.3-3217.4)/3217.4=0.1669 \times 100$ Water absorbed by the brick=16.69.% First class condition 1/6 of dry weight=1/6x3217.4=536.23g $536.23/3217.4=0.1667$ $=0.1667 \times 100=16.67\%$ 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 1/4 of its dry weight i.e. $1/4 \times 3217.4=804.35g$ $804.35/3217.4=0.25$ $=.25 \times 100=25\%$ Water absorbed by the brick is 16.69% less than (25%, hence the artisan brick from Lira is classified as class two.		$(M2-M1)/M1=388.6-333.4/333.4=54.2g$ $=54.2/333.4=0.162$ Water absorbed=0.162x100=16.2% First class condition 1/6 of dry weight=333.4/6=55.7 $=55.7/333.4 \times 100=16.66\%$ Water absorbed 16.2% less than 16.66% hence first-class and shows an improvement compared from the artisan brick.	

From this table of calculations, it is deduced that the slurry fractionation improves the class of the brick. This was the same with the Mukono clays.

Table 10. Efflorescence Test Results on Artisan, Improved chemical composition artisan and Improved Mould Bricks of Mukono and 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 [9, 13, 16]
1	Mukono artisan brick	20,000	4000	20%	Moderate
2	Lira artisan brick	29400	4500	15.30%	Moderate
3	Improved chemical artisan brick Mukono	3848.5	225	6%	Slight
4	Improved chemical artisan brick Lira	3848.5	2 475	12.3%	Moderate
5	Improved mould brick Mukono	19260	2899	15%	Moderate
6	Improved mould brick Lira	19270	2696.4	14%	Moderate

From this result table of efflorescence, it indicates that Mukono artisan brick had 20% covered by salt migration. After slurry fractionation,% coverage reduced to 6%. This reduction has been due to the disassociation of the salts and were eliminated as hydroxides hence reduction on the ability of the brick from absorbing much water which makes it of better class than before. The same happened with the Lira brick reduced from 15.3% to 12.3%.

4.2. Conclusions

The methods followed by the artisans in manufacturing of the clay bricks was established and found unsatisfactory

The earth chemical percentage composition of (Al₂O₃, SiO₂, Fe₂O₃ and CaO) used by the artisan in manufacturing clay bricks in Uganda was found.

Improvement on the percentage chemical of (Al₂O₃, SiO₂, Fe₂O₃ and CaO) was achieved in line with ideal composition for quality production through use of slurry fractionation.

Refining of raw clay using slurry fractionation method and

making bricks through use of constant force pressing molding is required as an intervention in the artisan manufacturing process to meet improved specific characteristic properties for durability, chemical stability and higher characteristic strength of clay bricks.

4.3. Recommendations

The study recommends an intervention of refining raw clay and use of constant force pressing in molding of bricks in the artisan method on manufacturing to produce good quality clay brick for durability, chemical stability and higher required characteristic strength for design specification.

The Research recommends Ugandan Government to map areas rich in kaolinite clays in every sub-county to help artisans, access better quality of clay for better quality brick manufacturing. Research recommends artisans to get training in clay brick manufacturing before engaging in manufacturing.

Recommend further research on clay for production of

structural pre-stressed sections and medicinal activities on skin diseases.

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