

# **ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS**

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**A FINAL YEAR RESEARCH AND DESIGN PROJECT REPORT SUBMITTED TO THE  
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**UGANDA CHRISTIAN  
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## **ABSTRACT**

This final year research and design project report provides an account of the research that was carried out from October 2024 to April 2025 in partial fulfilment of the requirements for the award of the degree of bachelor of science in civil and environmental engineering under the course unit final year research and design project. The report entails an introduction in chapter one that gives a background to the study, provides a statement of the problem, defines the objectives of the proposal in addition to stating the justification of the research and the scope of the research. In chapter two, the report provides the literature that was reviewed in order to identify the knowledge gap in the proposed research. The report also entails the employed methodology which identified the materials and methods that were used to achieve the specific objectives of research in addition to providing and discussed the results that were obtained thereafter.

## DECLARATION

I hereby declare that this is my original work, is not plagiarized and has not been submitted to any other institution for any award.

Signature: \_\_\_\_\_

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S21B32/069

## APPROVAL

I certify that this report is for KAKANDE HANNINGTON and I fully accept that he has been under supervision and so submitted to the Faculty of Engineering, Design and Technology of Uganda Christian University in partial fulfilment of the requirements for an award of a Bachelor of Science in Civil and Environmental Engineering.

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

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## **DEDICATION**

This final year research and design project report is dedicated to my family who have always taught me that it is important to have full knowledge, through studying, before commencing any venture.

## ACKNOWLEDGEMENT

Great glory and thanks be to the Almighty God who blessed me both with life, knowledge and ability to be able to carry out this research project within the required duration.

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## LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
BS	British Standard
CEBs	Compressed Earth Bricks
EN	European Norm
GD	Granite Dust
GM	Grading Modulus
Gs	Specific gravity
ISSBs	Interlocking Stabilized Soil Bricks
kg	Kilogram
$\text{kgm}^{-3}$	Kilogram per metre cubed
kN	Kilonewtons
LL	Liquid Limit
LSL	Linear Shrinkage Limit
mm	Millimetre
MPa	Mega Pascals
NASH	Sodium Aluminosilicate Hydrate
%	Percent
PI	Plasticity Index
PL	Plastic Limit
SS	Sodium Silicate

## CHAPTER ONE: INTRODUCTION

### 1.1. BACKGROUND

Unfired clay bricks are masonry units made from a process in which after molding the clay into desirable shape, the bricks are only sun-dried and not baked in a kiln (Muheise-Araalia and Pavia, 2020). These bricks address the vital issue of the environmental impact of fired clay bricks during the process of sintering hence prevent carbon dioxide emission to the atmosphere (Shaik et al., 2023). Unfired clay bricks also hence promote energy efficiency as shown by previous research where they have been noted to have 14% of the embodied energy of fired clay bricks and 25% of the embodied energy of concrete blocks (fultonbrickyardadmin, 2023). Just like the traditional clay bricks, unfired clay bricks can be used with most other building systems, tied to other structures, loaded with floors and roofs, fixed with insulation materials and services (Labaied et al., 2022). Considering the current state of research on unfired clay bricks, innovative solutions such as Interlocking Stabilized Soil Bricks (ISSBs) and Compressed Earth Bricks (CEBs) have presented the opportunity of using durable construction masonry units but these solutions however make use of expensive construction materials such as cement which dramatically raises the manufacturing costs (Raj et al., 2023). Previous studies however have evaluated that clay meant for manufacturing unfired clay bricks mixed with other materials led to improved soil composition, increased compressive strength and reduced water absorption that met the relevant international standards (Turgut and Algin, 2021). Therefore, it is on this premise that this research study undertakes to assess the suitability of sodium silicate-activated granite dust in the manufacturing of unfired clay bricks.

## 1.2. PROBLEM STATEMENT

In Budondo sub-county, Jinja district, a study showed that brick making is not feasible in the area due to the poor local soil's characteristics since it contained a lot of silt-clay and less sand particles hence leading to brick failure during curing and shrinkage cracking (Harriet et al., 2021). According to the study, this has left approximately 36.3% of the dwellings resorted to temporary wall building materials or incurring high transportation costs from neighbouring sub-counties due to the scarcity of bricks. In a study by Arasa et al. (2021), blending the local soil with sand and gravel (1:2 ratio) to produce burnt clay bricks resulted in bricks with marginal compressive strength (**2.3N/mm<sup>2</sup>, below the 5N/mm<sup>2</sup> minimum limit according to BS:3921-1985**) and exceeded water absorption capacity (**19.5%, above the 18% maximum limit according to EN 1996-2:2006**), failing to meet durability standards. Besides that, traditional burnt clay brick production emits carbon dioxide during kiln firing which contributes to climate change (Singh et al., 2024). There is need therefore, in Budondo sub-county, of more sustainable bricks with enhanced water absorption and compressive strength. One of the materials researched and used extensively in soil modification for brick making is granite dust in its raw form and not commonly as a geopolymer. It has also been noted that low compressive strength geopolymer is usually obtained for studies that employed granite and secondary activators in brick making because of lack of an optimal mix ratio between the two materials (Joshi, 2023). To solve this issue, granite dust may be activated with a secondary activator but in the required suitable amount. This project therefore was aimed at assessing the suitability of sodium silicate-activated granite dust in the manufacturing of unfired clay bricks.

### **1.3. RESEARCH OBJECTIVES**

#### **1.3.1. MAIN OBJECTIVE**

To assess the suitability of sodium silicate-activated granite dust in the manufacturing of unfired clay bricks.

#### **1.3.2. SPECIFIC OBJECTIVES**

1. To determine the physical and chemical properties of the local clay soils for brick making in Budondo sub-county.
2. To determine the physical and chemical properties of the granite dust, chemical properties of the sodium silicate and hence determine the optimal mix ratio of sodium silicate to granite dust.
3. To determine the effect of sodium silicate-activated granite dust on the physical properties, chemical properties and load-bearing capacity of the unfired clay bricks.

#### **1.3.3. RESEARCH QUESTIONS**

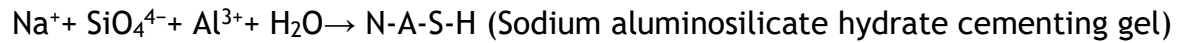
1. What are the physical and chemical properties of the local clay soils for brick making in Budondo sub-county?
2. What are the physical and chemical properties of the granite dust, chemical properties of the sodium silicate and hence what is the optimal mix ratio of sodium silicate to granite dust?
3. What is the effect of sodium silicate-activated granite dust on the physical properties, chemical properties and load-bearing capacity of the unfired clay bricks?

#### 1.4. JUSTIFICATION

Studies have shown that soils with high silt-clay content often hold poor gradation (Tang et al., 2022). To enhance their geotechnical properties, granite dust addition can turn the mix into a well graded complex that yields a high confinement (Amulya, Moghal and Almajed, 2021) to make it suitable for brick making. This is because adding granite dust to silt-clay soil allows for formation of a **rigid framework** within the soil through interlocking of the coarser particles while the clay particles themselves coat and bind the coarse grains to fill voids hence improving particle contact but while also maintaining plasticity for moulding of the overall matrix (Damaraju Lakshmi Lavanya et al., 2023). This helps to improve compressive strength and reduce water absorption of the final brick product (Amulya, Moghal and Almajed, 2021).

However, increased granite dust content can lead to failure of the mixture through decreasing the plastic nature of the clay soil. Geopolymerizing granite using sodium silicate activator can therefore provide a binder that chemically stabilizes the mixture. It **glues together** the particles of clay and granite thereby improving the overall cohesion, compressive strength and resistance to water absorption through the formation of a cementitious gel through the geopolymerization process (Castillo et al. 2022). In this process, the granite dust which contains aluminosilicate was activated using sodium silicate in alkaline conditions of sodium hydroxide in the presence of water. This leads to the breaking of the aluminosilicate bond to release free aluminate and silicate ions in solution. These free ions re-organize in solution to form a strong three dimensional network with a negative charge. The re-organized free silicate ions in particular attract and react with the free sodium ions in solution to form sodium

aluminosilicate hydrate (N-A-S-H) that binds together the soil-granite dust matrix. The sodium silicate hydrate is the cementing gel and was formed according to the following equation (Amulya, Moghal and Almajed, 2021):



To achieve strong polymerization for balanced mechanical properties and durability in brick production however, the concentration of sodium silicate required to activate granite dust needs to be **optimized** (Ridha, 2024).

### 1.5. SIGNIFICANCE

Traditional burnt clay brick production emits carbon dioxide during kiln firing which contributes to climate change (Singh et al., 2024) and at the same time existing technologies of unfired clay bricks utilize expensive construction materials such as cement which raises brick manufacturing costs (Raj et al., 2023). The findings of this research were therefore aimed at obtaining a solution that can integrate sustainable and eco-friendly brick production. Utilizing granite dust, which is typically is a waste product (Chajec, 2023), will reduce the need for virgin materials in brick production hence lowering brick manufacturing costs. The manufacturing of unfired bricks will also eliminate the need for high temperature firing, conserving energy and reducing carbon dioxide emissions, aligning with sustainable construction practices.

Furthermore, this project, if published, will also contribute to the existing body of knowledge to be utilized by researchers in addition to being an alternative method of brick production that could be used in the construction industry.

## **1.6. SCOPE OF RESEARCH**

### **1.6.1. CONTENT SCOPE**

This research was focused on assessing the suitability of sodium silicate-activated granite dust in the manufacturing of unfired clay bricks. The research culminated with determining the compliance of the manufactured bricks in relation to required standards of compressive strength, water absorption capacity, efflorescence and bulk density.

### **1.6.2. GEOGRAPHICAL SCOPE**

The area of study was Budondo sub-county, Jinja district. The area is located in eastern Uganda and is approximately 10.2km from the region's capital (AM, 2024).

### **1.6.3. TIME SCOPE**

This research took a period of 7 months from October 2024 upto April 2025.

## **CHAPTER TWO: LITERATURE REVIEW**

### **2.1. INTRODUCTION**

This chapter discusses the theoretical foundations upon which this progress report for this research was built and centred. The chapter also highlights the important discoveries from analyzing different scholar's findings.

### **2.2. PHYSICAL AND CHEMICAL PROPERTIES OF CLAY SOILS FOR BRICK MAKING**

#### **2.2.1. CLAY SOILS FOR BRICK MAKING**

Clay is fine grained earth that can be molded when wet and can be made to form a final desirable shape when dried or baked (Vieira, Sánchez and Monteiro, 2008). Clay can be used to make products such as bricks, pottery and ceramics. Clay is usually formed as a product of prolonged chemical weathering of silicate bearing rocks or locally from hydrothermal activity (Wimpenny, 2016). By composition, clay soil is a mixture that mainly comprises clay particles, silt and a small amount of both humus and sand particles (Wimpenny, 2016). Clay soil too has variations in itself by composition and this can be due to a number of factors that include but are not limited to climate, topography, land use and soil type (Kang et al., 2024). This therefore implies that clay soil can be unique in its properties such as cation exchange, plasticity, permeability and swelling behaviour based on the prior mentioned factors. In conclusion therefore, clay soil can be used for different purposes as mentioned earlier on because of these various properties. For the purpose of manufacturing bricks however, because of the same properties mentioned earlier on, we can find that not all clay soil is suitable

but it can however be modified using special methods in order to make it good enough for use in structural masonry (Wimpenny, 2016).

## **2.2.2. PHYSICAL PROPERTIES OF CLAY SOILS FOR BRICK MAKING**

### **2.2.2.1. PARTICLE SIZE DISTRIBUTION OF CLAY SOILS**

Particle size distribution is a laboratory test that is used to classify soils, especially coarse soils, in that it presents the relative proportions of different sizes of particles (Kang et al., 2024). From this, it is possible to determine whether the soil is predominantly gravel, sand, silt or clay sizes, and to a limited extent, which of these size-ranges is likely to control the engineering properties of the soil (Polakowski et al., 2021). In this test, appropriate sieves with a receiver at the bottom are arranged in order of decreasing aperture and the sample of soil placed at the top. By hand, the sieves are shaken for a sufficient period of time to separate the sample into different size fractions. The results of analysing particle size distribution are then plotted on a chart, where conventionally the vertical axis is the cumulative percentage (by weight) that is finer than a specific size, and the horizontal axis is the particle size plotted on a log scale (Polakowski et al., 2021). For the purpose of making bricks, clay soil should have a good blend between the silt, sand and clay particles where the clay should be about 20-30%, the silt should be about 30-50% and the sand should be about 20-30% as well (George Oluwole Akintola et al., 2024). The logical understanding behind aiming for these standards is to prevent shrinkage and deformation due to having too many fines or prevent reducing plasticity for moulding due to having too many coarse particles.

#### **2.2.2.2. ATTERBERG LIMITS OF CLAY SOILS**

The Atterberg limits of clay soils are the three laboratory tests on clay that enable us obtain its three physical properties of liquid limit, plastic limit and finally the linear shrinkage limit. The two tests of liquid limit and plastic limit can eventually be used to obtain the plasticity index of the clay soil which could indicate its ability to be easily moulded or worse still the ease of its flow in water conditions (Andrade, Al-Qureshi and Hotza, 2011). Given the fact that it is known that the plasticity index is the most important aspect of Atterberg limits of clay soils, the standard value especially if the soil is to be used for brick making ought to be known and this value according to literature has been found to be around 15-35% (Wikipedia Contributors, 2019). It is important to analyze Atterberg limits in the laboratory because the final value of these key aspects tested for can be used to define the ability of the clay to flow easily under conditions where there is a lot of water or its inability to be moulded into desirable shape or even crack easily under the dry conditions all with a final aim in mind of deciding upon which method to use to improve the mechanical properties of the soil and prevent it from cracking during drying or firing (Wikipedia Contributors, 2019).

#### **2.2.3. CHEMICAL PROPERTIES OF CLAY SOILS FOR BRICK MAKING**

##### **2.2.3.1. CHEMICAL COMPOSITION OF CLAY SOILS**

By virtue of the minerals that make up the rocks from which clay soils are formed by weathering, most clay soils usually comprise silica, alumina, magnesia and water (Chindaprasirt et al., 2012). In some cases, iron can substitute either aluminium or magnesium in varying degrees and to some extent, it has been noted that clay can have an appreciable quantity of calcium, potassium and sodium (Wang et al., 2023). The

main reasons why the clay soil can vary in its chemical composition is temperature and precipitation where precipitation dissolves minerals and salts in soil to move these down through the soil profile while temperature influences the nature of plants and organisms in the soil that cause biological weathering. For suitable making of bricks, clay needs to comprise 50-60% silica in order to increase rigidity so as to improve the overall strength of the bricks, 20-30% alumina in order to improve plasticity and reduce water absorption, 5-6% iron oxide so as to improve the brick's final appearance in terms of colour and 1-5% lime in order to prevent popping and weakening of the entire brick structure (Wang et al., 2023).

#### **2.2.3.2. SPECIFIC GRAVITY OF CLAY SOILS AND GRANITE DUST**

Specific gravity of a material according to literature refers to the ratio of the density of that material to the density of water (Ricca Chemical Company, 2018). It can be used to communicate the ability of a material to be fitted within a given volume, that is to say, when it is high, it implies that a greater mass of material can be packed into a given volume and when it is low, it implies that a small mass of material can be packed into a given volume. Greater specific gravity can therefore speak to the compressive strength if a material is used to form a brick product such that when it is low, the compressive strength is low and vice versa even in the event of water absorption capacity. The typical range of specific gravity in the case of clay soil about 2.6 to 2.8 and for granite dust 2.6 to 3.2 (Wright, 2022).

## **2.3. PHYSICAL AND CHEMICAL PROPERTIES OF THE SODIUM SILICATE-ACTIVATED GRANITE DUST**

### **2.3.1. SODIUM SILICATE**

According to literature, sodium silicate is one of the most important silicates for various industrial uses. The factory name of the material is “water glass” and by nature is supplied as a colourless and highly viscous fluid that is valued for its adhesive properties (A. Rabbii, 2001). By composition, sodium silicate is made up of the colourless oxide compounds of sodium and silicate (A. Rabbii, 2001). Over a number of years, this material has been formed by reacting compounds containing sodium carbonate with silica sand at high temperatures and then commonly applied as an agent to stabilize borehole walls in the process of drilling areas with clay minerals. The material is a suitable binder that can be used as a glue to other materials when in concentrated aqueous solutions but should be handled with care because it can strongly irritate the skin and the eyes (Phoo-ngernkham et al., 2015).

### **2.3.2. CHEMICAL PROPERTIES OF SODIUM SILICATE**

#### **2.3.2.1. CHEMICAL COMPOSITION OF SODIUM SILICATE**

By definition, any variety of compounds containing silicon, oxygen and sodium can be generically termed as sodium silicate and by chemical formula can be represented as  $\text{Na}_2\text{O} \cdot (\text{SiO}_2)_x$  (Lucas et al., 2011). From close observation of the stated chemical formula, it can be noted that sodium silicate compounds are only a given ratio  $x$  of silicon dioxide ( $\text{SiO}_2$ ) to sodium oxide ( $\text{Na}_2\text{O}$ ) by weight (Lucas et al., 2011). This chemical composition hence allows for sodium silicate compounds to react with pozzolanic materials containing elements such as aluminium, calcium, magnesium and

other metal ions in order to form geopolymers that are important binding and cementing gels for various applications say for example calcium or magnesium silicate hydrates in structural materials such as concrete (Lucas et al., 2011).

### **2.3.3. GRANITE DUST**

By definition, granite dust can be referred to as fine aggregates that are formed as a result of crushing aggregates from rocks made up of the mineral granite (Kouam et al., 2022). Processing of these aggregates usually happens in bulk at stone quarries that have advanced technology to reduce the particle size of stones to small sized aggregates. By composition, granite dust is mainly made up of compounds of oxide such as silica, alumina, potassium oxide, lime, iron, magnesia and titania as some of the key elements with these compositions varying depending on the key factor of location of origin (Kouam et al., 2022). Being a material made up of fine aggregates, granite dust can also be tested for its properties just like soil particles through performing tests such as particle size distribution, Atterberg limit tests and tests for its chemical properties. By application based on the suitability of this material upon carrying out the above mentioned laboratory tests, granite dust can be used as an alternative to cement in concrete when used as a geopolymer, it is also used as a filler in road pavements and also for construction of paths and or paved driveways (Danupon Tonnayopas and Kalayane Kooptarnond, 2007).

### **2.3.4. ACTIVATED GRANITE DUST**

Activated granite dust can be defined as fine aggregates of granite composition that have been activated either mechanically or chemically in order to increase their reactivity (Medina et al., 2017). In the mechanical activation process of granite dust,

it can further be crushed into smaller sized particles in order to increase the surface area for chemical activation using secondary activators. Chemical activation is what truly enables the granite dust to form a geopolymer especially when this is done in the presence of sodium hydroxide solution. There are a number of chemical activators from literature that have been used in the formation of geopolymers such as rice husk ash, ground granulated blast furnace slag among others but sodium silicate remains one of the components upon which research should be done in order to determine its suitability in activating granite dust (Medina et al., 2017).

### **2.3.5. SODIUM SILICATE**

From literature, sodium silicate can be defined as an inorganic substance that is usually colourless in appearance and is made up of the two chemical compounds of silica and sodium oxide (Andrés Martínez and Miller, 2023). On the market, it is usually sold under the factory name sodium metasilicate or water glass. It takes on the chemical formula  $(\text{Na}_2\text{O})_x\text{SiO}_2$  where the numerical value of  $x$  represents the ratio of sodium oxide to silica and can be from 1 up to 32 (Zhang et al., 2022). Sodium silicate can be obtained in two major ways which include collecting it from areas where it occurs naturally or through extracting it from materials containing silica in them for example silica sand, fly ash, ground granulated blast furnace slag and silica fume to mention but a few (P.U. Nzereogu et al., 2023). For the former however, it would require a highly alkaline environment to generate the sodium silicate for example that found along the northern shores of Lake Chad in Chad. Because of its adhesive nature, sodium silicate is commonly used as a binder in many products including detergents and also in cements as an activator for polymerization (Ridzuan, Khairulniza and Arshad, 2014). In addition

to this, because of its high silica content, sodium silicate is capable of reacting readily with materials made of compounds rich in cationic metals such as magnesium, calcium and aluminium among others in order to form insoluble compounds that are also good binding and water resisting agents through the process of geopolymerization (Ridzuan, Khairulniza and Arshad, 2014).

## **2.4. PHYSICAL PROPERTIES, CHEMICAL PROPERTIES AND LOADING BEARING CAPACITY OF UNFIRED CLAY BRICKS**

### **2.4.1. CLAY BRICKS**

By definition, clay bricks are masonry units that are formed as a result of mixing clay together with a given amount of water (Abbas et al., 2017). The final brick product itself is made using various hardening methods that could include but are not limited to air drying, sun drying and industrial ovens all with the aim of increasing the strength of the brick by removing water content within the clay that could easily make the matrix loose (Abbas et al., 2017). Clay bricks have been used over a number of year by mankind as masonry units specifically for accomplishing the task of construction of structures because they are cheap, durable and also have a well-defined rectangular shape on all faces hence making them easy to be stacked one over another so as to ensure building stability (Lachheb, Youssef and Zohir Younsi, 2023).

### **2.4.2. UNFIRED CLAY BRICKS**

Unfired clay bricks by definition can simply be defined as clay bricks that are not baked in a kiln but are instead left to dry on their own under the effect of the hot temperatures under the sun (Muheise-Araalia and Pavia, 2020). In most cases, because

this type of clay bricks has been deemed to be weak according to literature, are used for decorative purposes but with modifications of clay however through using additives could easily have their properties enhanced to suit other purposes (S. Daisylin Anbu Sujitha et al., 2023). The fact that it is possible to make unfired clay bricks also implies that it makes them more advantageous because these can greatly reduce the negative environmental impact through eliminating the cutting down of trees to burn bricks which is both an environment destroying and energy intensive process especially if the bricks are required in bulk for use as masonry units (Dr Priyank Singhal, 2019). The most common forms of unfired clay bricks are the Compressed Earth Bricks (CEBs) and the Interlocking Soil Stabilized Bricks (ISSBs) which make use of the expensive construction material of cement (Sølve Hov, Fredrik Falle and Paniagua, 2022). According to Danso et al (2014), more research therefore can be made in an effort to discover new ways on how to create these environmentally friendly unfired clay bricks using cheaper solutions however say using geopolymers for example (Lachheb, Youssef and Zohir Younsi, 2023).

### **2.4.3. PHYSICAL PROPERTIES OF UNFIRED CLAY BRICKS**

#### **2.4.3.1. COMPRESSIVE STRENGTH OF UNFIRED CLAY BRICKS**

According to standards from literature, it has been discovered that the most suitable compressive strength of a clay brick, especially when it is to be used as a masonry unit for the purposes of construction, ought to have a value of about 5 MPa (Oti, Kinuthia and Bai, 2009). From literature as well, the compressive strength in the specific case of an unfired clay brick has been noted to be highly dependent on the material properties used in making the clay brick, the dimensions of the wall and the overall

water content of the brick (Muheise-Araalia and Pavia, 2020). This therefore implies that the above mentioned aspects ought to be in check in the process of manufacturing the final brick product. The most important steps that can be undertaken in an effort to achieve the required high compressive strength of a clay brick especially if it is to be unfired can comprise the use of chemical modifications of the soil coupled together with appropriate curing techniques in order for the brick to yield full strength (Oti, Kinuthia and Bai, 2009).

#### **2.4.3.2. WATER ABSORPTION CAPACITY OF UNFIRED CLAY BRICKS**

From literature, it has been keenly noted that most suitable water absorption capacity, especially if the clay brick is to be used as a masonry unit for construction of structures, ought to be in the range of 12.5% minimum to 15% maximum (Bakar, Saari and Surip, 2017). The given range is as stated simply because if a clay brick to be used as a masonry unit takes in too much water, it can make the final brick product to easily lose its strength through reducing the cohesion between clay particles that may become loose to the extent of sliding over each other to cause failure of the brick and any structures therefore built using brick of its nature (Giaccone, Santamaria and Corradi, 2020). As a matter of fact, high water a high absorption capacity by the clay bricks can easily lead to erosion of the entire clay brick matrix through allowing for flow of the clay soil (Giaccone, Santamaria and Corradi, 2020). In conclusion therefore, modification in order to enhance the water absorption capacity of clay brickwork through efforts to reduce the water uptake ought to be done in order to increase the overall durability of clay bricks to be used as masonry units for construction of structures.

### **2.4.3.3. BULK DENSITY OF UNFIRED CLAY BRICKS**

From literature, it has been discovered that most suitable value of bulk density, especially if clay bricks are to be used as masonry units for construction of structures, ought to be around  $2000 \text{ kg/m}^3$  (Mawra et al., 2023). In simple explanation, bulk density of a clay brick simply defines the weight of clay bricks that can be accommodated within a specific volume or space. The bulk density value of bricks for masonry units indeed is required to be low because it defines the weight of dead load by the bricks which could result into structural collapse in case the bricks are too heavy (Junior, Teixeira and Mateus, 2024). In conclusion therefore, the final brick product manufactured for use as masonry units should always be of low weight per unit volume.

### **2.5.4. CHEMICAL PROPERTIES OF UNFIRED CLAY BRICKS**

#### **2.5.4.1. EFFLORESCENCE OF UNFIRED CLAY BRICKS**

By definition, efflorescence can be termed as the appearance of white deposits that form on the outer surface of a clay brick primarily due to the migration of soluble salts within the clay from the inner surface of the brick (Kizinievič et al., 2018). In testing for efflorescence, the bricks ought to be submerged under distilled water for a period of about one week and then their appearance is observed afterwards against an unsubmerged clay brick (Kizinievič et al., 2018). According to literature in relation to the aforementioned steps, there is supposed to be no formation of white deposits on the outer surface of the clay bricks (Kizinievič et al., 2018). An effort through research and design should therefore be made in order to modify any manufactured clay bricks such that they can maintain their aesthetics even when under salty environments that are capable of enhancing the likelihood of efflorescence (Kizinievič et al., 2018).

## **2.5.5. LOAD BEARING CAPACITY OF MASONRY UNITS [UNFIRED CLAY BRICKS]**

### **2.5.5.1. STRUCTURAL LOAD BEARING CAPACITY OF UNFIRED CLAY BRICKS**

The structural load bearing capacity of clay bricks can be established by employing crushing tests on a short course of wall just with the aim of determining the performance of a stack of bricks that have been bonded together for their ability to resist vertical shear forces (Dawood et al., 2021). According to literature, it can be noted that the clay brick load bearing capacity ought to be between the standard range of  $7.5 \text{ N/mm}^2$  minimum and  $10 \text{ N/mm}^2$  maximum if it is to be used as a masonry unit for the construction of structures (Oti, Kinuthia and Bai, 2009). In order to be capable of enhancing the load bearing capacity of clay bricks, the clay bricks must be manufactured in order to have a high compressive strength and must as well be cured appropriately under the most suitable conditions in order for them to yield maximum strength (Dawood et al., 2021).

## CHAPTER THREE: METHODOLOGY

### 3.1. INTRODUCTION

This chapter discusses the procedures, methods and materials which were employed in order to meet the specific objectives of the project.

### 3.2. MATERIALS AND METHODS OF THE STUDY

#### 3.2.1. MATERIALS OF THE STUDY

**(i) Clay soil**

The soil was sampled from Budondo sub-county at longitude 0.496509 and latitude 33.20401 since the clay soil found to be unfeasible for brick making was also sampled at this location. Sampling was done according to BS EN ISO 22475-1 at a depth of 2m in disturbed form using a hoe and a shovel. 200kg of soil were collected and these were air-tight sealed in 5 different sacks for storage. The soil sample was also air dried to remove moisture from the soil.

**(ii) Sodium silicate**

The sodium silicate was synthesized from silica fume that was sourced from MMI steel industry. About 500kg was obtained and sealed in air tight bags for storage. For preparation, the silica fume was washed with distilled water to remove dissolved impurities. The silica fume was then air dried for a week and magnetic separation was used to remove any metallic impurities. The silica fume was added to concentrated sodium hydroxide solution. Stirring was done to create a homogeneous mixture. The mixture was left to stand still for about 6 to 12 hours. The silica fume in solution that

does not react was sieved with polypropylene microfiber filter (cloth filter) allowing for collection of liquid sodium silicate in a container placed at the bottom of the sieve.

**(iii) Sodium hydroxide solution**

Concentrated sodium hydroxide solution was sourced from Jinja Marine Supplies.

**(iv) Granite dust**

The granite dust was sourced from MM Stone Quarry in Buyala village in Budondo sub county. 1000kg of granite dust was obtained and sealed in air tight sacks for storage. The material was sieved in order to ensure that its fraction passes the sieve number 200 (0.075mm) before being activated with sodium silicate or being mixed with the clay soil.

### **3.2.2. METHODS OF THE STUDY**

#### **DETERMINATION OF THE PHYSICAL AND CHEMICAL PROPERTIES OF THE LOCAL CLAY SOILS FOR BRICK MAKING IN BUDONDO SUB-COUNTY**

##### **3.2.2.1. Particle size distribution of local clay soil**

The test was carried out in reference to BS 1377: Part 2: 1990 using the method of sieve analysis. The purpose of this test was to determine how much of each particle size was present in the local clay soils of Budondo sub-county. This was to aid in making computations for proper blending with the granite dust.

**Required equipment:** BS test sieves, metal tray, drying oven, scoop, weighing balance, riffle box.

## Procedure

1. The clay soil was passed through sieves whose aperture was decreasing and the weight retained on each sieve was noted.

Sample retained = weight of sample on the sieve - weight of sieve without sample

2. The recorded data was used to calculate the cumulative percentage passing each sieve.

Percentage retained = (mass retained) ÷ (initial sample mass) x 100%

Cumulative percentage passing = 100% - percentage retained

3. A graph was plotted on a log scale and the obtained results used to compute the fineness modulus that was used as a measure of course to fine particles in the clay soil.

Grading modulus =  $\frac{[300 - (\text{percentage retained on } 2\text{mm} + 0.425\text{mm} + 0.075\text{mm})]}{100}$

### 3.2.2.2. Atterberg limits of local clay soil

The test was carried out in reference to BS 1377: Part 2: 1990 using the method of cone penetration for obtaining the liquid limit and then further tests to obtain the plastic limit by rolling the soil into threads. The purpose of these tests was to determine the plastic properties of the clay soils for workability when molding bricks and their effect to resist shrinkage that could lead to cracking of the bricks. This was to aid in making computations for proper blending with the local clay soil.

**Required equipment:** BS test sieves, metal tray, drying oven, scoop, weighing balance, riffle box, cone penetrometer.

### **Procedure for the liquid limit**

1. A BS cone penetrometer fitted with an automatic timing device that ensures 5 second penetration under an 80g load was used.
2. An oven-dried representative specimen from the clay soil sample was pounded and sieved through a 0.425 mm BS test sieve, after which 200g of each specimen passing the 0.425 mm BS test sieve was mixed thoroughly with distilled water and the water was allowed to permeate it overnight in an air tight container.
3. The respective specimens were then remixed the following day with sufficient water to achieve two penetrations in the range between 15mm and 25mm.
4. The moisture content for each of the pastes was recorded. A moisture content penetration curve was drawn from which the moisture content at 20 mm penetration was taken as the liquid limit.

### **Procedure for the plastic limit and plasticity index**

1. The specimens used for the tests were prepared in the same manner as those for the liquid limit tests. The test consisted of rolling a ball of soils paste from each sample between the hands and then into threads between the palm and a glass plate.
2. The plastic limits for the respective specimens were recorded as the moisture contents at which the threads develop transverse cracks when they were about 3mm diameter.
3. The plasticity index is the numerical difference between the LL and PL that is to say  
$$PI = LL - PL$$

### **3.2.2.3. XRF for chemical composition of local clay soil**

The test was carried out in reference to ASTM D8438-23 using the method of XRF spectrometry. The purpose of this test was to determine the chemical compounds present in the clay soil so as to compare it to material of brick making standards.

**Required equipment:** X-ray spectrometer, X-ray analyser

#### **Procedure**

1. The sodium silicate-activated granite dust was exposed to x-rays using an x-ray spectrometer.
2. An x-ray analyser was used to capture the fluorescent x-ray signals emitted from the sample. The signals when analyzed by the x-ray analyser was used to determine the chemical composition of the clay soil.

### **3.2.2.4. Specific gravity of local clay soil**

The test was carried out in reference to BS 1377: Part 2: 1990 using the pyknometer method. The purpose of this test was to determine the density of the clay soil sample relative to that of water at room temperature.

**Required equipment:** Pyknometer, weighing balance, water

#### **Procedure**

1. The mass of the pyknometer (M1) and also later on the mass of the pyknometer with dry clay soil (M2) was established using a measuring scale.
2. The pyknometer mass, water and clay soil sample (M3) and the mass of the pyknometer together with water (M4) was also established using a weighing scale.

3. The overall specific gravity of the clay soil sample was established from the formula:

$$\text{Specific gravity } G_s = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)}$$

## DETERMINATION OF THE PHYSICAL AND CHEMICAL PROPERTIES OF THE GRANITE DUST, CHEMICAL PROPERTIES OF THE SODIUM SILICATE AND HENCE DETERMINATION OF THE OPTIMAL MIX RATIO OF SODIUM SILICATE TO GRANITE DUST

### 3.2.2.5. Particle size distribution of activated granite dust of that suitable proportion

The test was carried out in reference to BS 1377: Part 2: 1990 using the method of sieve analysis. The purpose of this test was to determine how much of each particle size was present in the sodium silicate-activated granite dust. This was to aid in making computations for proper blending with the local clay soil.

**Required equipment:** BS test sieves, metal tray, drying oven, scoop, weighing balance, riffle box.

#### Procedure

1. The sodium silicate-activated granite dust was passed through sieves whose aperture is decreasing and the weight retained on each sieve was noted.

Sample retained = weight of sample on the sieve - weight of sieve without sample

2. The recorded data was used to calculate the cumulative percentage passing each sieve.

Percentage retained = (mass retained) ÷ (initial sample mass) × 100%

Cumulative percentage passing = 100% - percentage retained

3. A graph was plotted on a log scale and the obtained results used to compute the fineness modulus that was used as a measure of course to fine particles in the sodium silicate-activated granite dust.

$$\text{Fineness modulus} = \frac{\text{Sum of percentage retained on all sieves}}{100}$$

#### 3.2.2.6. Specific gravity of granite dust

The test was carried out in reference to BS 1377: Part 2: 1990 using the pyknometer method. The purpose of this test was to determine the density of the granite dust sample relative to that of water at room temperature.

**Required equipment:** Pyknometer, weighing balance, water

#### Procedure

1. The mass of the pyknometer (M1) and also later on the mass of the pyknometer with dry granite dust (M2) was established using a measuring scale.
2. The mass of the pyknometer, the water and the granite dust sample (M3) and the mass of the pyknometer together with water (M4) was also established using the weighing scale.
3. The overall specific gravity of the granite sample was established from the formula:

$$\text{Specific gravity } G_s = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)}$$

#### 3.2.2.7. Chemical characterisation test on the granite dust

The test was carried out in reference to ASTM D8438-23 using the method of XRF spectrometry. The purpose of this test was to determine the chemical compounds

present in the granite dust and this will henceforth be used to determine the suitability of the material relative to a natural pozzolan for geopolymerization.

**Required equipment:** X-ray spectrometer, X-ray analyser

#### **Procedure**

1. The granite dust was sieved through a 2mm sieve to produce fine material.
2. The granite dust was exposed to x-rays using an x-ray spectrometer.
3. An x-ray analyser was used to capture the fluorescent x-ray signals emitted from the sample whereby the signals when analyzed by the x-ray analyser was used to determine the chemical composition of the granite dust.

#### **3.2.2.8. Chemical characterisation test on the prepared sodium silicate**

The test was carried out in reference to ASTM D8438-23 using the method of XRF spectrometry. The purpose of this test was to determine the chemical compounds present in the granite dust and this will henceforth be used to determine the suitability of the material relative to the standards of a chemical activator.

**Required equipment:** X-ray spectrometer, X-ray analyser

#### **Procedure**

1. A portion of prepared sodium silicate was obtained and filtered through the cloth filter to remove any impurities.
2. The granite dust was exposed to x-rays using an x-ray spectrometer.
3. An x-ray analyser was used to capture the fluorescent x-ray signals emitted from the sample.

### **3.2.2.9. Compressive strength of the geopolymer of sodium silicate-activated granite dust.**

The test was carried out in reference to ASTM C349 as a means of determining the compressive strength of mortar prisms made from the sodium silicate-activated granite dust so as establish the best mix proportion for activating the granite dust.

**Required equipment:** A weighing scale, mixing equipment such as trowels, molds, a compaction tool, a room temperature curing chamber, a compressive strength testing machine.

#### **Procedure**

1. Sodium silicate-activated granite dust geopolymer was prepared from mixing varying proportions of prepared sodium silicate with granite dust for example in varying ratios of 70:30, 50:50 and other several trial mixes. This was done using mixing with a constant amount of water in order to determine the effect of the sodium silicate on the granite dust.
2. The inner surfaces of the molds were greased with oil in order to allow for easy removal of the geopolymer from them. Tamping and vibration was done in order to ensure that there are no air voids in the mortar. The molds were levelled off with mortar.
3. The molds were allowed to set for a period of about 24 hours.
4. The specimens were demolded and then be placed in an oven for a period of 24 hours at about 60°C to 80°C for the formed geopolymer to completely set.
5. The specimens were tested for compressive strength.

6. This test was done about 3 times for each mixing ratio of the sodium silicate and the granite dust.

### **3.2.2.10. Water absorption capacity of the geopolymer of sodium silicate-activated granite dust.**

This test was done with reference to EN 1996-2:2006 using the Cobb method. The test was to aid in determining the amount of water that can be absorbed by the geopolymer of sodium silicate-activated granite dust within a given period of time.

**Required equipment:** Weighing scale, stop watch

#### **Procedure**

1. The geopolymer of sodium silicate-activated granite dust was weighed in air on a weighing scale and its weight, W<sub>1</sub> was recorded and noted.
2. The geopolymer of sodium silicate-activated granite dust was soaked in water for a period of 24 hours and its weight, W<sub>2</sub> was determined using the weighing scale. The weight was noted and recorded.
3. The average water absorption capacity of the geopolymer of sodium silicate-activated granite dust was determined from triplicate tests using:

$$\text{Water absorption capacity} = \frac{W_1 - W_2}{W_1} \times 100\%$$

## **DETERMINATION OF THE EFFECT OF SODIUM SILICATE-ACTIVATED GRANITE DUST ON THE PHYSICAL PROPERTIES, CHEMICAL PROPERTIES AND LOAD-BEARING CAPACITY OF THE UNFIRED CLAY BRICKS**

### **3.2.2.11. Mix design**

1. This was done through making computations of the appropriate mix ratios of clay to granite dust to activator using the standard brick size of Budondo sub-county.
2. This mix design by ratio of weight of each material component was considered as the optimal mix ratio. The brick was a semi-dry mix between clay and granite dust of dimension 228.6mm by 127.4mm by 76.2mm. The diagram is via Appendix C.
3. The major properties of compressive strength of the unfired clay bricks and water absorption capacity were tested each time in comparison to a control sample.

### **3.2.2.12. XRF for chemical composition of mix between soil and granite dust**

The test was carried out in reference to ASTM D8438-23 using the method of XRF spectrometry. The purpose of this test was to determine the chemical compounds present in the mix of the sodium silicate-activated granite dust and the soil.

**Required equipment:** X-ray spectrometer, X-ray analyser

#### **Procedure**

1. Blending of the soil and the sodium silicate-activated granite dust was done in order to determine suitable proportions and weights of mixing the two materials.
2. The sodium silicate-activated granite dust and soil mix was exposed to x-rays using an x-ray spectrometer.
3. An x-ray analyser was used to capture the fluorescent x-ray signals emitted from the sample. The signals when analyzed by the x-ray analyser was used to determine the chemical composition of the sodium silicate-activated granite dust and soil mix.

### **3.2.2.13. Compressive strength of bricks**

This was done in reference to reference to BS:3921-1985 through applying a compressive vertical load until failure and the failure load over the gross area of the brick. The test was used to determine the maximum vertical load that the manufactured unfired clay bricks can withstand.

**Required equipment:** Universal testing machine (UTM)

#### **Procedure**

1. The manufactured unfired clay brick was placed between the platens of the universal testing machine and the vertical load being applied to it was increased gradually until the brick failed.
2. The reading of the UTM at the point of failure was considered to be the compressive strength of the unfired clay bricks.

### **3.2.2.14. Water absorption capacity of bricks**

This test was done with reference to EN 1996-2:2006 using the Cobb method. The test was to aid in determining the amount of water that can be absorbed by the unfired clay bricks within a given period of time.

**Required equipment:** Weighing scale, stop watch

#### **Procedure**

1. The brick was weighed in air on a weighing scale and its weight,  $W_1$  was recorded and noted.
2. The brick was soaked in water for a period of 24 hours and its weight  $W_2$  determined.

3. The water absorption capacity of the brick was determined from

$$\text{Water absorption capacity} = \frac{W_1 - W_2}{W_1} \times 100\%$$

4. The test was done in triplicates in order to get an average value for consistent and reliable results.

### **3.2.2.15. Bulk density of bricks**

This test was done with reference to BS EN771-1.

**Required equipment:** Drying oven, foot ruler

#### **Procedure**

1. The soaked brick was oven dried at 105<sup>0</sup>C until it reached constant mass.
2. The brick was put out of the oven and be allowed to cool down to room temperature.
3. The bricks dimensions were measured carefully and its volume measured.
4. The bulk density of the brick was obtained from: Bulk density =  $\frac{\text{Dry mass}}{\text{Volume}}$  . The bulk density should be about 2.5g/cm<sup>3</sup>.
5. The test was done in triplicates in order to get an average value for consistent and reliable results.

### **3.2.2.16. Efflorescence of bricks**

This test was done with reference to BS EN771-1. The test was used to determine the level of efflorescence of submerged bricks relative to those that have not been submerged. Efflorescence is a naturally occurring process caused by moisture carrying salts from the inside of the brick to the surface (Sidhu and Kumar, 2023).

**Required equipment:** Water, drying oven

## **Procedure**

1. Ten bricks were selected at random and they were submerged in water of depth of about 25.4mm.
2. The bricks were placed in a drying room to allow the bricks to react with water internally for about 24 hours.
3. The bricks were oven dried for about 24 hours at 105<sup>0</sup>C and they were examined for efflorescence relative to those that had not been submerged.
4. The level of efflorescence was to be rated as nil for no noticeable efflorescence, trace for barely noticeable efflorescence, slight for efflorescence being visible but its appearance is not noticeable at 6 feet away, moderate when the bricks have a distinct coating but the original colour is still visible and considerable if the original colour of the brick is masked by efflorescence.

### **3.2.2.17. Structural load bearing capacity of bricks**

This test was done with reference to BS 5628 part 1 1992 and EN 1996.1.1.2005 using the diagonal compression method.

**Required equipment:** Universal Testing Machine (UTM), measuring tape

## **Procedure**

1. Unfired clay brick samples were prepared using the optimum amount of sodium silicate-activated granite dust and their dimensions of length, width and height was measured and recorded.
2. A wall panel made of three courses of the final brick product with the most suitable properties was considered. The bricks of the wall were bound together by general

purpose mortar of strength 2.5MPa and were subjected to vertical loading at an angle of 45<sup>0</sup>.

3. The maximum load displayed by the monitors connected to the UTM at the point of brick failure was noted and recorded. This failure load was considered to be the load bearing capacity of the short course wall.

## CHAPTER FOUR: RESULTS AND DISCUSSION

### 4.1. INTRODUCTION

This chapter presents the results from the tests carried out on the study materials.

### 4.2. SUMMARY OF RESULTS

Table 4-1: Summary of laboratory test results for specific objective 1

MATERIAL	CHARACTERISTIC TESTED	PARAMETER TESTED	VALUE OBTAINED	REQUIRED STANDARD
CLAY SOIL	PHYSICAL	Liquid limit	49.1%	25 to 38%
		Plastic limit	32.3%	12 to 22%
		Plasticity index	16.8%	7 to 16%
		Linear shrinkage	10.4%	15 to 25%
		Particle size	95.2% clay/silt and 4.8% sand	25 to 50% clay/silt and 20 to 45% sand
	Specific gravity	2.61	2.6 (min.)	
	CHEMICAL	Silica	10.834%	50 to 60%
		Alumina	5.705%	20 to 30%
		Iron oxide	10.201%	Less than 7%
		Lime	7.070%	2 to 5%
Magnesia		4.923%	Less than 1%	

The standards used for the properties of clay required for brickmaking were according to the **Green brickmaking manual**.

Table 4-2: Summary of laboratory test results for specific objective 2

MATERIAL	CHARACTERISTIC TESTED	PARAMETER TESTED	VALUE OBTAINED	REQUIRED STANDARD
GRANITE DUST	PHYSICAL	Particle size	0% fines	-
		Specific gravity	2.72	2.6 (min.)
	CHEMICAL	Silica content	72.300%	70 to 77%
		Alumina content	14.653%	11 to 13%
		Iron oxide	1.732%	2 to 3%
		Sodium	3.121%	3 to 5%
		Calcium carbonate	1.901%	1 to 2%
		Magnesium	0.474%	Less than 1%
SODIUM SILICATE	CHEMICAL	Silica : Sodium ratio	1.29	From 1 up to 3
SODIUM SILICATE-ACTIVATED GRANITE DUST CUBES	PHYSICAL	Compressive strength	9.74 MPa	-
		Water absorption capacity	2.4%	-

Table 4-3: Summary of laboratory test results for specific objective 3

MATERIAL	CHARACTERISTIC TESTED	PARAMETER TESTED	VALUE OBTAINED	REQUIRED STANDARD
FINAL BRICK PRODUCT	PHYSICAL	Compressive strength	4.92 MPa	5 MPa (min.)
		Water absorption capacity	13.75%	18% (max.)
		Efflorescence	Nil	Nil
		Load bearing capacity	118.1 kN	100 to 150 kN
		Particle size	4.5% fines	25 to 50% clay/silt and 20 to 45% sand
		Liquid limit	34.7%	25 to 38%
		Plastic limit	24.1%	12 to 22%
		Plasticity index	10.6%	7 to 16%
	Linear shrinkage	8.2%	15 to 25%	
	CHEMICAL	Silica content	59.07%	50 to 60%
		Alumina content	29.61%	20 to 30%
		Iron oxide	4.90%	Less than 7%
		Lime	2.30%	2 to 5%
		Magnesium	0.63%	Less than 1%

The standards used for the properties of granite dust and activated granite dust were according to the **Neolith technical manual** and the **Geopolymer concrete book 978-620-3-58292-5** respectively.

The standards used for the properties of the brick products were according to the **Green brickmaking manual**.

#### 4.3. CLAY SOIL SAMPLE FROM BUDONDO SUB-COUNTY IN JINJA DISTRICT

##### 4.3.1. PARTICLE SIZE DISTRIBUTION OF THE CLAY SOIL

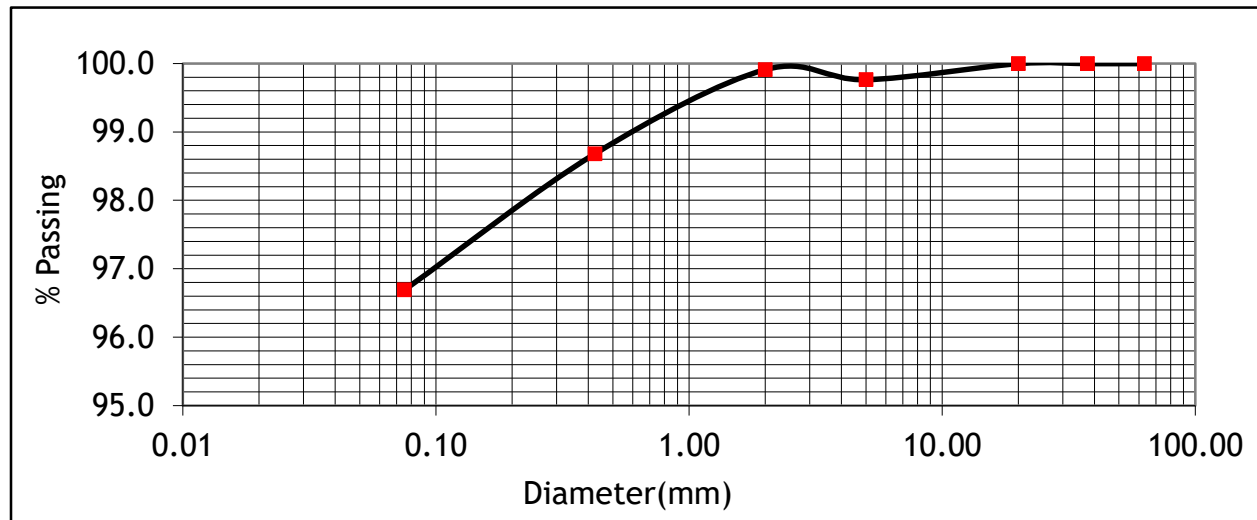


Figure 4-1: Grading curve of the clay soil sample from Budondo sub county in Jinja district

From the average of triplicate tests carried out on the soil sample from Budondo sub-county, the particle size distribution test using the method of sieve analysis was used to plot the graph above. From the grading curve, it was observed that the average silt-clay fraction of the soil was 93.9% and the remaining proportion was constituted by fine sand fraction. According to **Green brickmaking manual**, preferable soil proportions for brick making ought to be 25 to 50% clay/silt and 25 to 45% sand. This is because clay

for brick making needs a good balance between the coarse and fine particles to allow for both proper molding and good strength (AGBEDE and MANASSEH, 2008). From the above discussion, the soil was found to be fine as shown by the grading modulus computed below which is a ratio of coarse to fine material in a soil sample (Zhong et al., 2024).

The grading modulus of the clay soil was obtained using the formula:

$$\text{Grading modulus} = \frac{[300 - (\text{percentage passing on } 2\text{mm} + 0.425\text{mm} + 0.075\text{mm})]}{100} \quad \dots \text{Eqn. 1}$$

$$\text{Grading modulus} = \frac{[300 - (99.7 + 98.4 + 93.9)]}{100} = 0.08 \quad \dots \text{Eqn. 2}$$

This grading modulus was interpreted using the criteria in Table 4-4:

Table 4-4: Grading modulus in soil and their meaning (Sourced from CALIFORNIA DEPARTMENT OF TRANSPORTATION (CAL TRANS) UNIFIED SOIL CLASSIFICATION SYSTEM UNIFIED SOIL CLASSIFICATION AND SYMBOL CHART)

Grading modulus	Soil type	Description
Less than 1.5	Fine grained soils	Very fine soils such as silts or clays
1.5 to 3.0	Medium grained soils	Well-graded soil or silty sand
Greater than 3.0	Coarse grained soils	Coarse soils such as gravel or sandy gravel

Therefore, the grading modulus showed that fine particles in the clay soil sample were in great quantity compared to the coarse particles and hence there was need to increase the amount of coarse particles in the clay soil so to make it suitable for brickmaking. Fine grained particles are usually too small and too smooth to allow for binding through interlocking hence leading to formation of weak and brittle bricks (Yasir and Jebur, 2023).

#### 4.3.2. ATTERBERG LIMITS OF THE CLAY SOIL

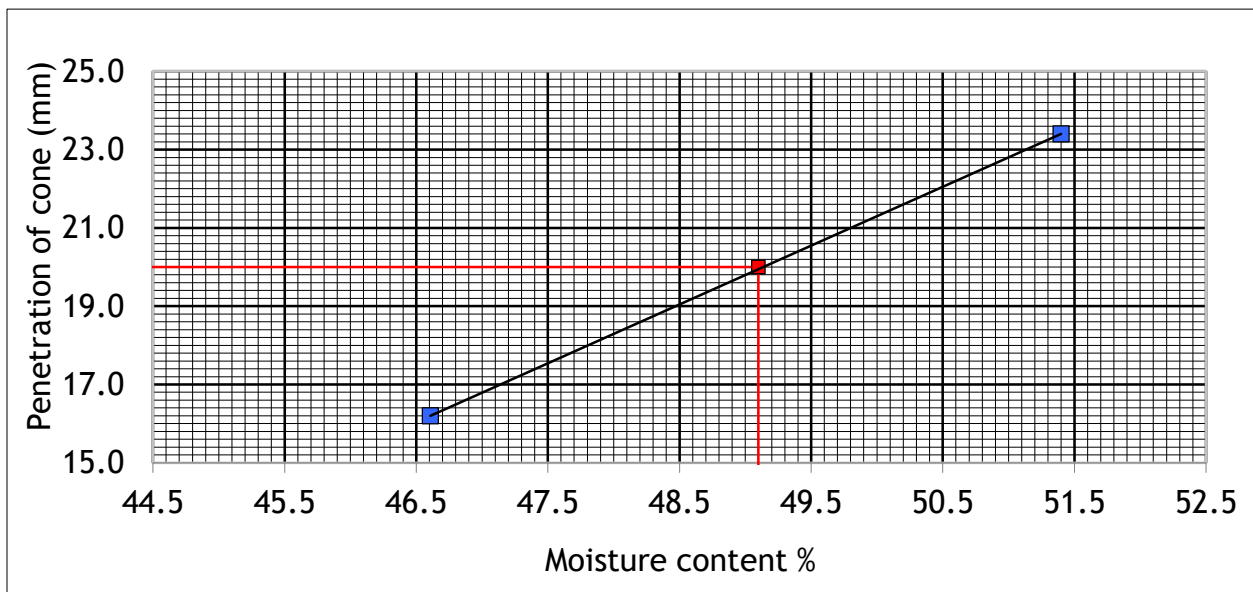


Figure 4-2: Liquid limit of the clay soil sample from Budondo sub county in Jinja district

From the average of test results obtained from the Atterberg limits of the clay soil, it was observed that the clay soil had an average liquid limit of 48.9% with the average plastic limit being 32.1% hence leading to an average plasticity index of 16.8%. The average linear shrinkage was discovered to be 10.2%. According to the **Green brickmaking manual** however, soil material for brick manufacturing should possess

about 25 to 38% liquid limit, 12 to 22% plastic limit and about 7 to 16% plasticity index and not more than 16% linear shrinkage. This is because such characteristics allow for easy molding of the material to be used for brick making while also indicating the materials ability to prevent uptake of excess water to cause swell or rapid drying to cause shrinkage cracking once molded into the final brick product (Miskir Gebre Hiwot, Quezon and Kebede, 2017). The clay soil of Budondo hence still showed according to this criterion that it was not suitable for brick making because it showed potential of suffering the above defects in the final brick product.

According to literature, the liquid limit of a soil sample can be defined as the maximum moisture content at which soil is capable of flowing under its own weight such that it passes from plastic state to liquid state (Hossain et al., 2021). It's the same moisture content at which the soil also then passes from liquid state to plastic state when drying. From the results obtained, this value was obtained as 48.9% which was beyond the standard maximum of 38% according to the **Green brickmaking manual** hence the soil was deemed to flow very easily in wet conditions. There was need therefore to ensure that the liquid limit of the soil sample was reduced to acceptable standards to prevent this effect. On the other hand, the plastic limit of a soil sample can be defined as the moisture content at which the soil passes from plastic to semi-solid state such that it becomes difficult to remold it without having to split it (Hossain et al., 2021). From the laboratory tests carried out, this value was obtained as 32.1% which was beyond the maximum standard of 22% according to the **Green brickmaking manual** hence the soil sample was deemed to be difficult to dry into semi-solid state but once there, it is also difficult to change it back to plastic state which was a good property of the soil.

Finally, there was the plasticity index which according to literature is the difference between liquid limit and the plastic limit of the soil sample that can be used to establish the extent to which the soil absorbs water (Hossain et al., 2021). A high plasticity index indicates that the soil sample is susceptible to large volume changes with change in moisture content (Abbey, Eyo Umo Eyo and Akinwumi, 2020). This characteristic is usually typical of soils with a high percentage of fines such as silt and clay (Kaliakin, 2009). In reference to the results obtained, the plasticity index was 16.8% which was slightly higher than the required maximum of 16% according to the **Green brickmaking manual** hence there was need to reduce this value slightly back to the allowable limits. Finally, the average Atterberg limits obtained were used to define the nature of the fine-graded soil from Budondo sub-county using the plasticity chart below.

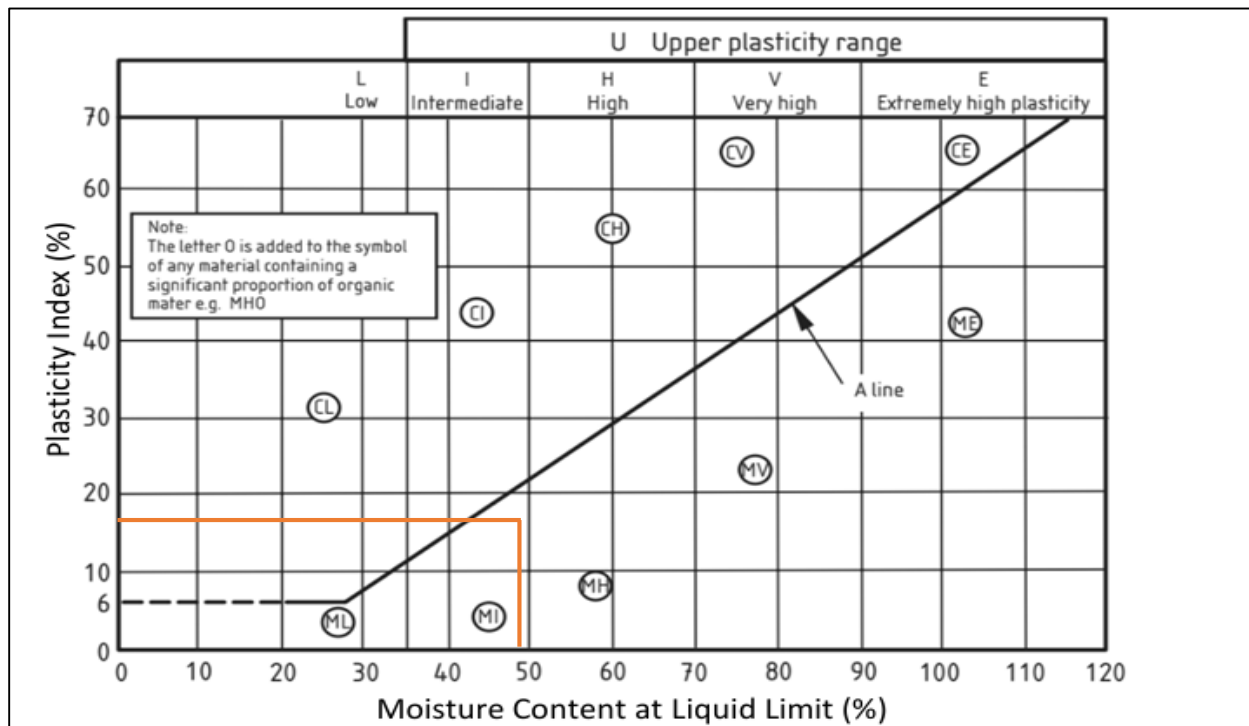


Figure 4-3: Atterberg limits results on a plasticity chart for the clay soil (Sourced from BS 5930:2015)

is a silty material with intermediate plasticity. This plasticity implies that the bricks shrink excessively during drying leading to cracking and warping hence it needed lowering (Hossain et al., 2021).

#### 4.3.3. CHEMICAL COMPOSITION OF CLAY SOIL

The chemical composition of the clay soil from Budondo sub-county in Jinja district was determined using the XRF test and its chemical elements were as shown in Table 4-5:

Table 4-5: Key mineral oxides in the clay soil from Budondo sub-county

Chemical compound	Composition (%)	Required standard (%)
Silica	10.834	50 to 60
Alumina	5.705	20 to 30
Iron oxide	10.201	Less than 7
Lime	7.070	2 to 5
Magnesia	4.923	Less than 1

From the results obtained, it was observed the silica content within the clay soil sample was low. According to literature, silica in clay soils for brick making acts as a binding agent within the clay mixture so as to ensure that the final shape of the brick product is maintained through enhancing brick strength and hardness (Zhang et al., 2022). According to the **Green brickmaking manual**, the standard value for silica content in clay for brick making should be about 50 to 60% in order to achieve this. This therefore indicated the need to increase the amount of silica in the clay soil sample to prevent the final brick product from cracking, shrinking and warping.

Furthermore, the amount of alumina within the clay brick was 5.705% which was less than the required minimum of 20% for brickmaking according to the **Green brickmaking manual**. Alumina in clay soil for brickmaking is very important because it enhances the ability of the clay to be molded into desirable shape (ganeshas, 2024). Lime that helps bricks harden during firing was less than the standard value but this was a non-issue since the bricks were to be unfired. The iron oxide in the clay soil was relatively high at 5.340% compared to the required maximum of 7% which gave the soil samples collected a light brown colour. The level of magnesia was 0.028% which was less than the required maximum of 1% which implied that final brick product was capable of resisting cracking during drying (Guzlena et al., 2019).

From the results obtained, upon considering the major oxides in the clay soil as stated above, the suitability index of the clay sample for brick making based on chemical composition was determined. In material suitability studies, the suitability index refers to a numerical value that represents how good enough a particular material is for application in specific fields based on its properties relative to the required standards (Ishlahul Fikri, Riani and Syahril Nedi, 2024).

Table 4-6: Suitability of the clay soil from Budondo sub-county for brick making relative to the brickmaking standards by chemical composition

KEY ELEMENTS	% FROM XRF TEST	REQUIRED STANDARD (GBM)	CLOSEST STANDARD	% DEV. $\frac{X - SD}{SD} \times 100$	% SUIT. $ 100 - \frac{\sum DEV.}{ELTS} $
Silica	10.834%	50 to 60%	50%	78.33	<b>25.85%</b>
Alumina	5.705%	20 to 30%	20%	71.48	
Iron oxide	10.201%	Less than 7%	7%	45.73	
Lime	7.070%	2 to 5%	5%	41.40	
Magnesia	4.923%	Less than 1%	1%	392.3	
Silica: Alumina	2:1				

Therefore, the soil from Budondo sub-county was unsuitable for brickmaking in its natural state by chemical composition and that it needed modification in order to be able to meet the required standards. The silica to alumina ratio of 2:1 also explains why the soil's plasticity is intermediate. This is because the silica and alumina sheets in this case are bonded by weak Van der Waals forces which allow for high water intake (Hansen, 2025), high soil swelling and shrinkage cracking of the final brick product when drying.

#### 4.3.4. SPECIFIC GRAVITY OF CLAY SOIL

By carrying out the specific gravity test on the clay soil, the ratio of the density of the clay soil sample relative to the density of that of water was established as shown in the Table 4-7 that was used to record the results below. Having obtained the specific gravity of the clay soil, the actual density of the clay soil sample was also established by multiplying through by  $1000\text{kgm}^{-3}$ . This value of density obtained was to be utilized in computing the mass of the clay soil sample to be incorporated into the final brick matrix by multiplying the volume to be taken by the clay soil sample by the density of the clay soil sample:

Table 4-7: Specific gravity of the clay soil sample from Budondo sub-county

CLAY SAMPLE FROM BUDONDO SUBCOUNTY		
Testing date	20/02/2025	
Test No.	1	2
Weight of the pyknometer (M1)g	101.926	101.926
Pyknometer and dry soil (M2)g	128.026	128.926
Pyknometer and dry soil and water (M3)g	218.526	219.227
Pyknometer and water (M4)g	202.464	202.532
Specific gravity $G_s = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)}$	2.60	2.62
Average specific gravity $G_s$	2.61	
Density of clay ( $\text{kgm}^{-3}$ )	2610	

The specific gravity of 2.61 means that the mass of a unit volume of soil solids at a given temperature is 2.61 times the mass of an equal volume of water at the same temperature.

#### 4.4. GRANITE DUST SAMPLE FROM MM STONE QUARRY IN BUDONDO SUB-COUNTY IN JINJA DISTRICT

##### 4.4.1. PARTICLE SIZE DISTRIBUTION OF THE GRANITE DUST

From the average of triplicate tests carried out on the granite dust sample from MM stone quarry, the particle size distribution test using the method of sieve analysis was used to plot the graph shown in Figure 4-4.

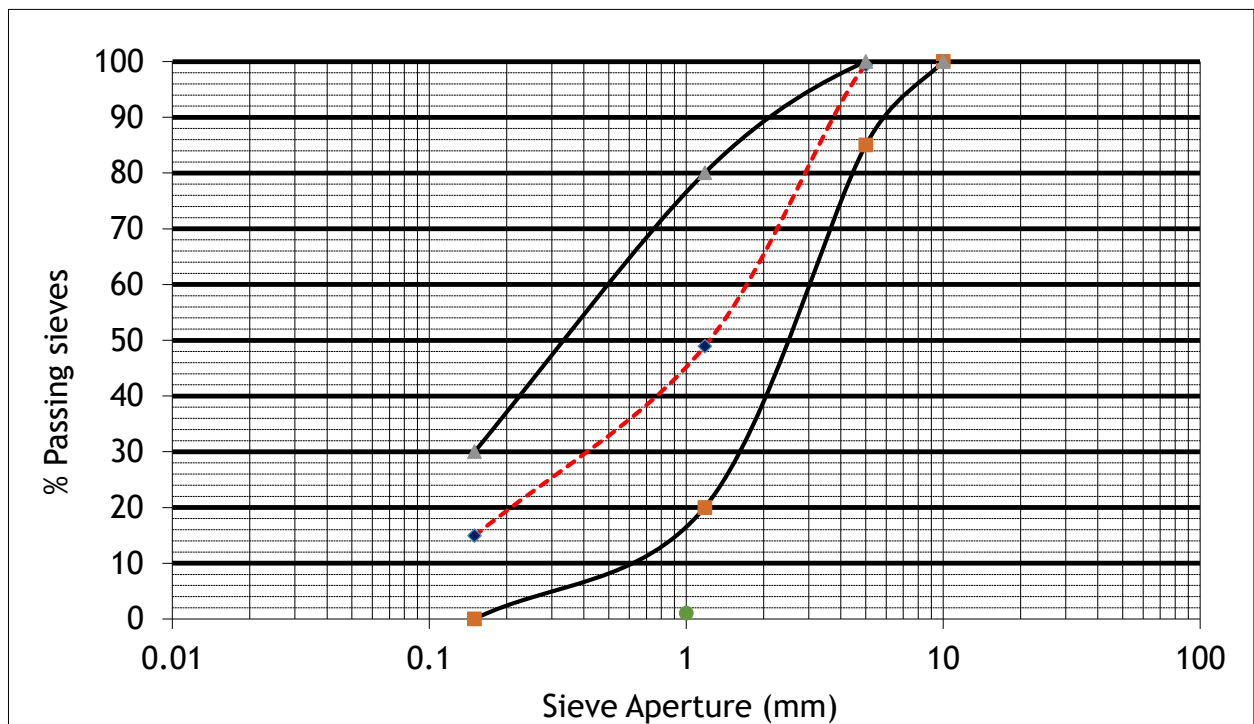


Figure 4-4: Grading curve of the granite dust sample from MM stone quarry in Budondo sub county in Jinja district

The fineness modulus of the clay soil was obtained using the formula:

$$\text{Fineness modulus} = \frac{[(\text{percentage retained on } 2\text{mm} + 0.425\text{mm} + 0.075\text{mm})]}{100} \quad \dots \text{Eqn. 3}$$

$$\text{Fineness modulus} = \frac{[(0.6+51.1+85.1)]}{100} = 1.368 \quad \dots \text{Eqn. 4}$$

The fineness modulus was interpreted using the criteria in Table 4-8:

Table 4-8: Recommended specification on granite fines (Sourced from Neolith technical manual)

Grading modulus	Soil type
0.6 to 1.5	Fine grained material
1.5 to 2.8	Medium grained material
2.8 to 4.0	Coarse grained material

Overall, the fineness modulus showed that the fine particles in the granite dust sample were in great quantity compared to the coarse particles. The value of 1.368 obtained however was found to be closer to 1.5 implying that though the material was fine which aids for incorporation into the clay soil, it was also to introduce a fair amount of coarse particles into the final brick matrix. This implies that the granite dust had the potential to allow for interlocking, increasing strength of the final brick product in addition to providing a platform for proper binding of clay materials (Yasir, 2025).

#### 4.4.2. SPECIFIC GRAVITY OF THE GRANITE DUST

By carrying out the specific gravity test on the granite dust, the ratio of the density of the granite dust sample relative to the density of that of water was established as

shown in the Table 4-9 that was used to record the results below. Having obtained the specific gravity of the granite dust, the actual density of the granite dust sample was also established by multiplying through by  $1000\text{kgm}^{-3}$ . This value of density obtained was also to be utilized in computing the mass of the granite dust sample to be incorporated into the final brick matrix:

Table 4-9: Specific gravity of the clay soil sample from MM stone quarry

GRANITE DUST SAMPLE FROM MM STONE QUARRY		
Testing date	20/02/2025	
Test No.	1	2
Weight of the pyknometer (M1)g	101.926	101.926
Pyknometer and granite dust (M2)g	235.049	235.053
Pyknometer and granite dust and water (M3)g	286.589	286.229
Pyknometer and water (M4)g	202.229	202.226
Specific gravity $G_s = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)}$	2.73	2.71
Average specific gravity $G_s$	2.72	
Density of granite dust ( $\text{kgm}^{-3}$ )	2720	

The specific gravity of 2.61 means that the mass of a unit volume of soil solids at a given temperature is 2.61 times the mass of an equal volume of water at the same temperature.

#### 4.4.3. CHEMICAL COMPOSITION OF THE GRANITE DUST

The chemical composition of the granite dust from MM stone quarry in Budondo sub-county was determined using the XRF test and its chemical elements were as shown in Table 4-10:

Table 4-10: Key mineral oxides in the granite dust from MM stone quarry in Budondo sub-county

Chemical compound	Composition (%)	Required standard (%)
Silica	72.301	70 to 77
Alumina	14.653	11 to 13
Iron oxide	1.732	2 to 3
Lime	1.863	1 to 2
Magnesia	0.474	Less than 1

For any material to be considered a natural pozzolan, the combined sum of silica, alumina and iron oxide should be about 70% (ASTM C618). This is because silica and alumina are the primary reactive components in the formation of geopolymer materials hence their presence in large quantities implies the potential for the process to occur. A high amount of silica allows for the formation of a strong three dimensional network of bonds that become crystalline over time to improve compressive strength and lower water absorption while alumina neutralizes the resultant negative charge on the silica (Habert, 2014). This all happens once chemical activation of the granite dust has occurred. In order to determine the overall suitability of the granite dust as a natural

pozzolan in comparison to the required standards, the suitability index was obtained as shown in Table 4-11:

Table 4-11: Suitability of the granite dust from MM stone quarry for brick making relative to the natural pozzolan standards by chemical composition

KEY ELEMENTS	% FROM XRF TEST	REQUIRED STANDARD (ASTM C618)	CLOSEST STANDARD	% DEV. $\frac{X - SD}{SD} \times 100$	% SUIT. $ 100 - \frac{\sum DEV}{ELTS} $
Silica	72.301%	70 to 77%	-	0	<b>94.78%</b>
Alumina	14.653%	11 to 13%	13%	12.72	
Iron oxide	1.732%	2 to 3%	2%	13.40	
Lime	1.863%	1 to 2%	-	0	
Magnesia	0.474%	Less than 1%	-	0	
Silica: Alumina	5:1				

Therefore, the granite dust from MM stone quarry in Budondo sub-county was found to be suitable for being able to undergo geopolymerization reactions in its natural state by chemical composition and that it needed modification in comparison to the required natural pozzolan standards.

#### 4.4.4. CHEMICAL COMPOSITION OF THE PREPARED SODIUM SILICATE

The chemical composition of the sodium silicate prepared from the silica fumes was determined using the XRF test and its chemical elements were as shown in Table 4-12:

Table 4-12: Chemical composition of the sodium silicate prepared from the silica fumes

Chemical compound	Concentration (g/l)
Silica	98.8
Sodium	76.4

For any material to be considered a suitable chemical activator for natural pozzolans, it should have a sufficient amount of silica that reacts to form the hydrated silicate gel which is the binding material (Sargent, 2015). This aspect can best be seen through modulus control where by a suitable activator should have a specific modulus for suitable reactivity with pozzolans and lowering of the setting time (Torres-Ortega, Torres-Sanchez and Lopez-Lara, 2024). Table 4-13 shows the modulus of the sodium silicate prepared compared to the recommendations as a natural pozzolan chemical activator:

Table 4-13: Modulus of sodium silicate

KEY COMPONENTS	DETECTION FROM XRF TEST (g/l)	% FROM XRF TEST
Silica	98.8	$\left(\frac{98.8}{98.8 + 76.4}\right) \times 100\% = 56.4\%$
Sodium	76.4	$\left(\frac{76.4}{98.8 + 76.4}\right) \times 100\% = 43.6\%$
Modulus of sodium silicate		$\frac{56.4}{43.6} = 1.29$
Standard modulus (J.L. Provis and J.S.J. Van Deventer, 2009)		1.0 to 3.0

From the obtained results therefore after analysis, the sodium silicate was found to be suitable enough for activating the granite dust since its modulus of silicate to sodium was falling within the recommended range.

#### 4.5. OPTIMAL MIX RATIO OF GRANITE DUST TO SODIUM SILICATE FOR COMPLETE GEOPOLYMERIZATION

##### 4.5.1. COMPRESSIVE STRENGTH OF THE CAST SODIUM SILICATE-ACTIVATED GRANITE DUST CUBES

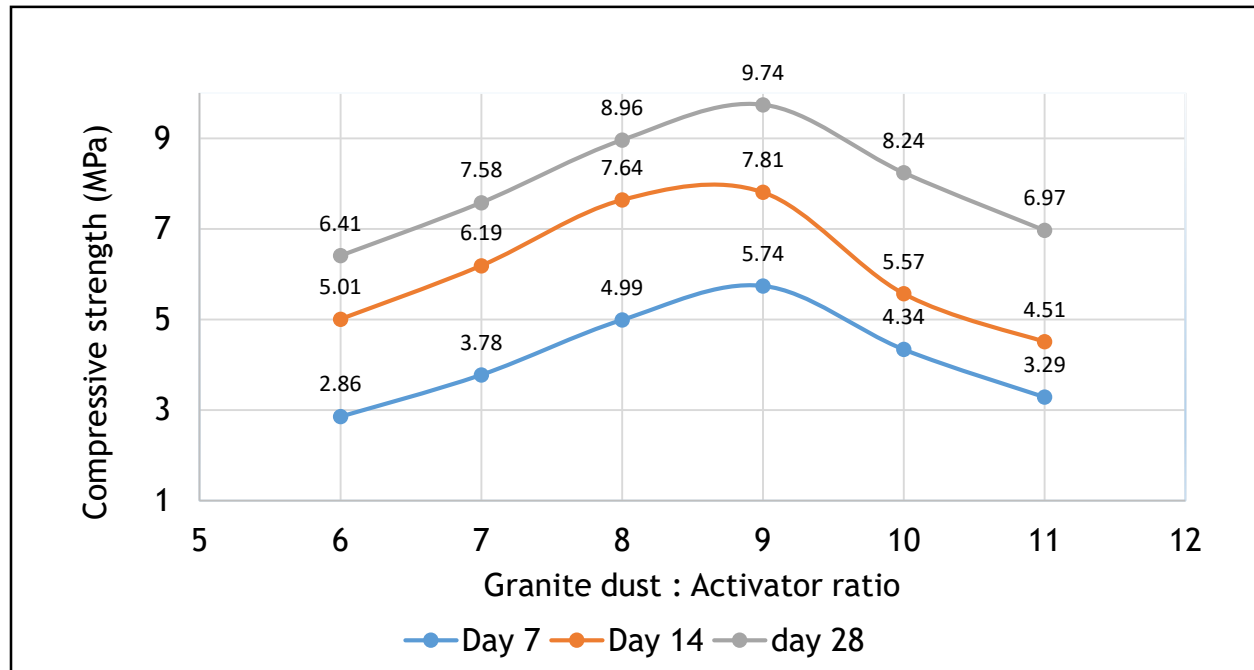


Figure 4-5: 28 day average compressive strength graph of the sodium silicate-activated granite dust cubes

Having cast the granite dust that had been activated by sodium silicate, these were subjected to a compressive strength test in order to determine what could have been the optimal mix ratio of granite dust to sodium silicate for complete geopolymerization. The logic used behind this approach was that at a point of complete geopolymerization, there would be maximum compressive strength of the dust unlike at points where the two materials were not in the correct proportion. The average of the compressive strength after 28 days of air drying, since it is a time at which full strength maturity is expected (Habert, 2014), was considered in this case.

These results were summarized and analyzed in table format as shown in Table 4-14:

Table 4-14: Mix proportions by mass of granite dust and sodium silicate for compressive strength test on the cubes

Trial mix number	Average compressive strength (MPa)	Granite dust to sodium silicate ratio	% change in compressive strength
1	6.41	6:1	0.00
2	7.58	7:1	18.25
3	8.96	8:1	39.78
4	9.74	9:1	51.95
5	8.24	10:1	28.55
6	6.97	11:1	8.74

Considering the graph for average compressive strength after 28 days, it was observed that by trend, there was an initial increase in the compressive strength of the cubes up to a maximum after which a drop in the compressive strength was noted. Mathematically, the compressive strength of the cubes had a linear relationship to the mix ratio between the granite dust and sodium silicate overall. The equation for correlation was  $y = 0.1589x + 6.633$  and the regression computed thereafter was 0.0568 which implies that only about 5.68% of the mix ratio of granite dust to sodium silicate can account for the increase in the compressive strength of the cubes. There hence could be other factors that can be attributed to the increasing compressive strength of

the cubes. The highest observed compressive strength on average after 28 days of air drying was 9.74 MPa which implied about 51.95% increase in the compressive strength at a granite dust to sodium silicate ratio of 9:1 as compared to the starting point where the mix ratio was 6:1.

The overall trend of the graph can be attributed to the fact that initially, when the granite dust to sodium silicate ratio is low, there is an excess of silicate ions from the sodium silicate and insufficient aluminate ions from the granite dust which not only creates an overly alkaline environment but also does not allow for sufficient neutralization reaction of the silicate ions by the aluminate ions (Abbas et al., 2017). This implies that there is no great extent of rearrangement of the aluminosilicate compound from the granite dust in the silicate solution hence leading to formation of an improper structured geopolymer network of sodium aluminosilicate hydrate (Dawood et al., 2021). Over time, as this network becomes crystalline in nature with air drying, it leaves voids which make the resultant geopolymer porous and weak and hence resulting into a product of low compressive strength because of low densification (Zhong et al., 2024). As the amount of granite dust increases, more aluminosilicate from the granite dust is introduced in to the silicate ions from the sodium silicate which allows for rearrangement of the aluminosilicate into a three dimensional network of sodium aluminosilicate hydrate upon breakdown over a large portion in the sodium silicate solution. This implies that more crystalline material is formed during air drying to form a denser and solid structure over time with increased compressive strength up to a maximum (Hossain et al., 2021). Beyond this maximum, the aluminosilicate from the granite dust then becomes the compound in excess relative to the silicate ions from

the sodium silicate. This implies that some part of the aluminosilicate from the granite dust remains undissolved in the sodium silicate. Most of the granite dust hence remains as dry unreacted material that cannot form crystals or densify on its own over time hence leaving behind voids that form pores which are points of weakness and lower the compressive strength of the fine cube product (ganeshas, 2024). This effect can only increase with increase in the amount of granite dust relative to sodium silicate hence giving reason for the decrease in the compressive strength beyond the optimal mix ratio (Dawood et al., 2021).

#### **4.5.2. WATER ABSORPTION CAPACITY OF THE CAST SODIUM SILICATE-ACTIVATED GRANITE DUST CUBES**

The cast sodium silicate activated-granite dust cubes were also subjected to a water absorption capacity test in order to determine what could have been the optimal mix ratio of granite dust to sodium silicate for complete geopolymerization. The logic used behind this approach was that at a point of complete geopolymerization, there would be minimum water absorption unlike at points where the two materials were not in the correct proportion.

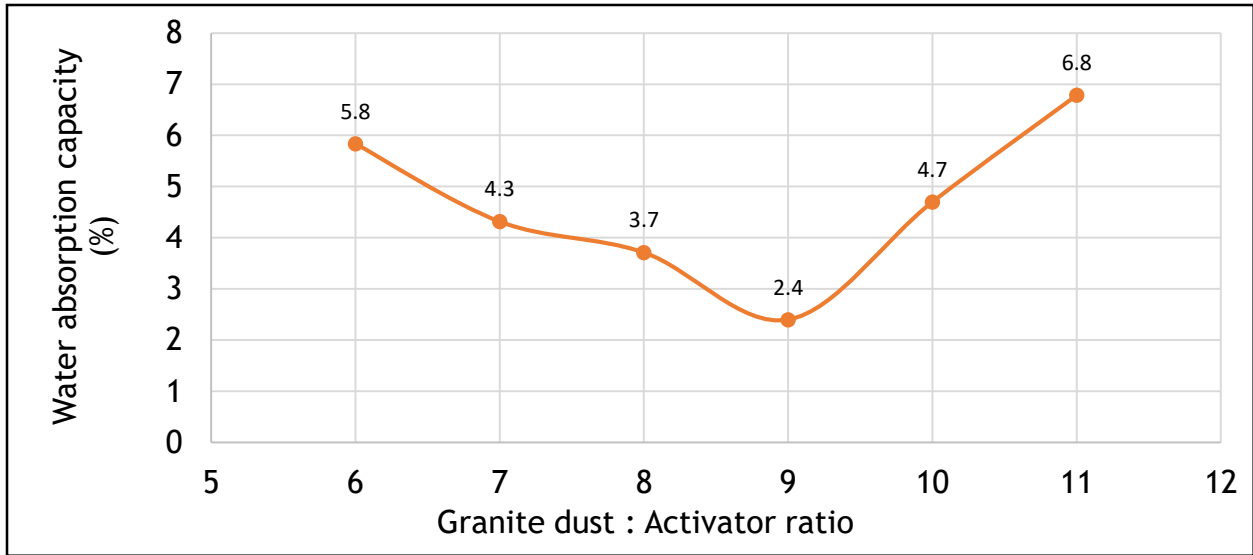


Figure 4-6: Average water absorption capacity graph of the sodium silicate-activated granite dust cubes at 28 days

These results were summarized and analyzed in Table4-15:

Table 4-15: Mix proportions by mass of granite dust and sodium silicate for water absorption capacity test on the cubes

Trial mix number	Average water absorption capacity (%)	Granite dust to sodium silicate ratio	% change in water absorption capacity
1	5.8	6:1	0.00
2	4.3	7:1	-25.86
3	3.7	8:1	-36.21
4	2.4	9:1	-58.62
5	4.7	10:1	-18.97
6	6.8	11:1	-17.24

Considering the graph for average water absorption capacity after 28 days, it was observed that by trend, there was an initial decrease in the water absorption capacity of the cubes up to a maximum after which a drop in the compressive strength was noted. Mathematically, the water absorption capacity of the cubes had a linear relationship to the mix ratio between the granite dust and sodium silicate overall. The equation for correlation was  $y = 0.1589x + 6.633$  and the regression computed thereafter was 0.0568 which implies that only about 5.68% of the mix ratio of granite dust to sodium silicate can account for the decrease in the water absorption capacity of the cubes. There hence could be other factors that can be attributed to the decreasing water absorption capacity of the cubes. The lowest observed water absorption capacity on average after 28 days of air drying was 2.4% which implied about 58.62% decrease in the water absorption capacity at a granite dust to sodium silicate ratio of 9:1 as compared to the starting point where the mix ratio was 6:1.

The overall trend of the graph can be attributed to a similar explanation as to why the compressive strength of the cubes increases up to a maximum and then decreases. The voids left initially by the improper network of the three dimensional aluminosilicate arrangement allow for entry of water into the cubes hence implying that they have a high water absorption initially. When the granite dust to sodium silicate ratio is increased however, a more appropriate three dimensional network is formed to allow for formation of solid crystals during air drying hence forming a water tight structure that reduces entry of water into the cubes up to a minimum (Dawood et al., 2021). The effect of excess aluminosilicate as the granite dust to sodium silicate ratio increases implies that most of the unreacted aluminosilicate does not form sodium silicate

aluminosilicate hydrate (cementing gel) but instead remains as fine solids to large extent that have a high affinity for water because of low densification (Guzlena et al., 2019).

#### **4.6. EFFECT OF SODIUM SILICATE-ACTIVATED GRANITE DUST ON THE PHYSICAL PROPERTIES, CHEMICAL PROPERTIES AND LOAD-BEARING CAPACITY OF THE UNFIRED CLAY BRICKS**

##### **4.6.1. MIX DESIGN FOR THE FINAL BRICK PRODUCT**

From the table below, it was established by calculation that blending the clay and granite dust in the stated proportions would allow for obtaining a material whose particle size was to be suitable enough for brick making. However, there was need to still establish the most suitable blend between the two materials hence necessitating carrying out various brick physical and chemical tests in order to identify the most suitable mixture by its properties.

The stated process started by establishing the amount of materials required for mixing each brick based on the densities of the clay and granite dust and the volume of the final brick product. After establishing the masses of the materials, the bricks were molded and the tests of water absorption capacity, compressive strength, bulk density, load bearing capacity, efflorescence were carried out in comparison to a control sample as well. The most suitable mixture as established from the above stated tests was then considered for the XRF test and carrying out of the particle size distribution and Atterberg limits tests in order to determine the chemical and physical properties of the final product that had been made from mixing clay with sodium silicate-activated

granite dust for brick making. Below are the results from each of the stated computations that were made during the process:

Table 4-16: Mix proportions for clay and granite dust from blending calculations

Sieve size (mm)	2.00			0.425			0.075		
Material	Clay	GD		Clay	GD		Clay	GD	
% pass	99.7	65.0	Total	98.4	30.0	Total	93.9	0.0	Total
Mix proportions (clay % & GD %)									
44 and 56	43.86	36.4	80.26	43.30	16.80	60.10	41.32	0.00	41.32
45 and 55	44.86	35.75	80.61	44.28	16.50	60.78	42.26	0.00	42.26
46 and 54	45.86	35.10	80.96	45.26	16.20	61.46	43.19	0.00	43.19
47 and 53	46.86	34.45	81.31	46.25	15.90	62.15	44.13	0.00	44.13
48 and 52	47.86	33.80	81.66	47.23	15.60	62.83	45.07	0.00	45.07
49 and 51	48.86	33.15	82.01	48.22	15.30	63.52	46.01	0.00	46.01
50 and 50	49.86	32.50	82.36	49.20	15.00	64.20	46.95	0.00	46.95
51 and 49	50.86	31.85	82.71	50.18	14.70	64.88	47.89	0.00	47.89
52 and 48	51.86	31.20	83.06	51.17	14.40	65.57	48.83	0.00	48.83
53 and 47	62.86	30.55	93.41	52.15	14.10	66.25	49.77	0.00	49.77
Target standard for brick making			80 - 100			50 - 80			20 - 50

The following steps were followed in the determination of the masses of clay soil, granite dust, sodium silicate and sodium hydroxide for manufacturing of the final brick product for each blend:

- (i) The density of the clay and granite dust materials were each established through laboratory testing
- (ii) Volume of the brick =  $228.6(\text{mm}) \times 127.4(\text{mm}) \times 76.2(\text{mm}) = 2.219 \times 10^{-3} \text{m}^3$
- (iii) Volume percentage of the brick taken up by clay = Clay % x volume of brick
- (iv) Volume percentage of the brick taken up by GD = GD % x volume of brick
- (v) Mass of clay = Volume of clay x density of clay
- (vi) Mass of GD = Volume of GD x density of granite dust
- (vii) Mass of sodium silicate =  $\frac{1}{10}$  (Mass of GD)
- (viii) Mass of sodium hydroxide solution =  $\frac{1}{3.5}$  (Mass of sodium silicate)

These steps produced the results in Table 4-17:

Table 4-17: Masses of the different components mixed together for making brick products for each clay and granite dust mix proportion

		MASS (kg)			
		Clay	Granite dust	Sodium silicate	Sodium hydroxide
Mix proportions (clay % & GD %)	Mix number				
44 and 56	1	2.548	3.380	0.338	0.097
45 and 55	2	2.606	3.320	0.332	0.095
46 and 54	3	2.664	3.260	0.326	0.093
47 and 53	4	2.722	3.199	0.320	0.091
48 and 52	5	2.780	3.139	0.314	0.090
49 and 51	6	2.838	3.078	0.308	0.088
50 and 50	7	2.896	3.018	0.302	0.086
51 and 49	8	2.954	2.957	0.296	0.085
52 and 48	9	3.012	2.897	0.290	0.083
53 and 47	10	3.070	2.837	0.284	0.081

#### 4.6.2. COMPRESSIVE STRENGTH OF THE FINAL BRICK PRODUCT

Having molded the bricks using various mix proportions by mass, these were subjected to a compressive strength test in order to determine the best mix proportion for

achieving maximum improvement for the final brick product. Figure 4-7 is a graphical representation of the results that were obtained:

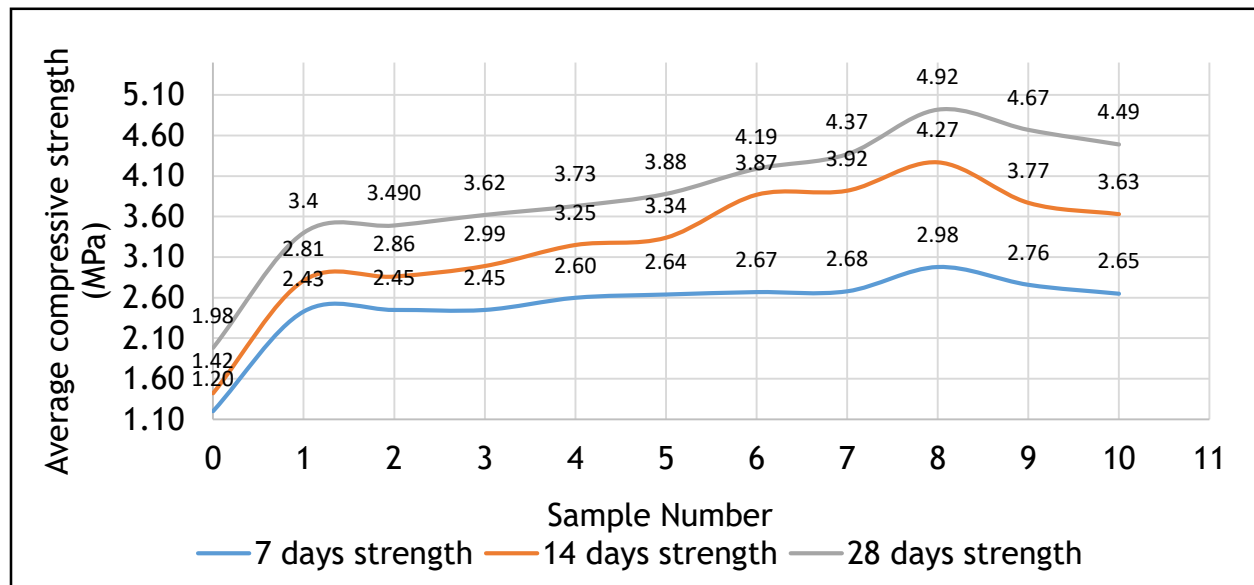


Figure 4-7: Average compressive strength graph of the final brick product for different mix proportions

From the Table 4-18, the control sample up to the peak increment for compressive strength at 51% clay and 49% granite dust mix proportions, the compressive strength was rising steadily till it reached a maximum because with increased clay content relative to the granite dust, there was better packing of materials as the fines filled the voids in the coarser material.

Table 4-18: Increments in the compressive strength of the final brick products

Mix number	Value	% Increment
Control	1.98	0.00
1	3.40	71.72
2	3.49	2.58
3	3.62	3.72
4	3.73	3.04
5	3.88	4.02
6	4.19	7.99
7	4.37	4.30
8	4.92	12.59
9	4.67	-5.08
10	4.49	-3.85

This led to increased densification of the final brick product hence allowing for better distribution of vertical loads and thus leading to higher compressive strengths (Ajiboye et al., 2022). The compressive strength also increased because chemically, the increasing clay content availed more aluminosilicate ions for reaction with the silicate ions from the sodium silicate hence allowing for formation of a high amount of sodium

aluminosilicate hydrate gel which when crystalline fills up pores to form a denser material with higher compressive strength as explained earlier on (Joshi, 2023). Beyond the maximum achieved compressed strength, there was a decrease in strength with increasing clay content because there was a high amount of fine particles in the mix that have low resistance to vertical load (Ni et al., 2004).

#### 4.6.3. WATER ABSORPTION CAPACITY OF THE FINAL BRICK PRODUCT

In order to supplement the compressive strength in search of the best mix material proportion, the water absorption capacity test was done in order to assess the behaviour of the final brick products with water. The results are as represented on the graph shown in Figure 4-8:

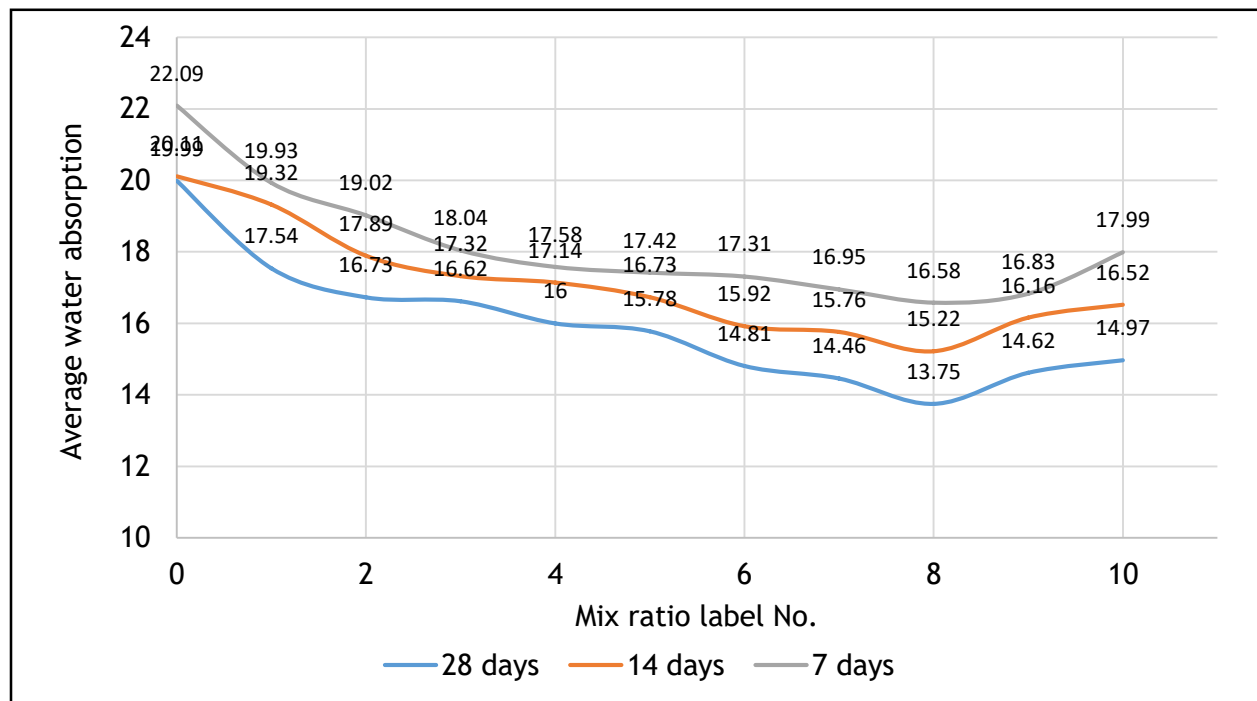


Figure 4-8: Average water absorption capacity graph of the final brick product for different mix proportions

From the control sample up to the peak decrement for water absorption capacity at 51% clay and 49% granite dust mix proportions, the water absorption capacity was reducing steadily till it reached a minimum because with increased clay content relative to the granite dust, there was better packing of materials as the fines filled the voids in the coarser material. This led to increased filling of voids of the final brick product hence allowing for reduced capillarity and hence less water movement into the brick (Zainuddin et al., 2019). The water absorption capacity also decreased because chemically, the increasing clay content availed more aluminosilicate ions for reaction with the silicate ions from the sodium silicate hence allowing for formation of a high amount of sodium aluminosilicate hydrate gel which when crystalline fills up pores to form a material with higher with lower capillarity and hence less water absorption capacity as explained earlier on (Clements et al., 2024). Beyond the minimum achieved water absorption capacity, there was an increase in water absorption capacity with increasing clay content because there was a high amount of fine particles in the mix that have a high affinity for water uptake (Zainuddin et al., 2019).

The percentage decrease in the water absorption capacity for the different mix proportions is as shown in Table 4-19:

Table 4-19: Decrements in the water absorption capacity of the final brick product for different mix proportions

Mix number	Value	%Decrement
Control	19.99	0.00
1	17.54	12.26
2	16.73	4.62
3	16.62	0.66
4	16.00	3.73
5	15.78	1.38
6	14.81	6.14
7	14.46	2.36
8	13.75	4.91
9	14.62	-6.33
10	14.97	-2.39

#### 4.6.4. EFFLORESCENCE OF THE FINAL BRICK PRODUCT

Efflorescence in bricks basically deals with making observations on the exposed areas of a brick so as to spot any salt deposits (Argha and Quazi, 2018). These simply make the brick aesthetically unsightly especially in moisturized environments. The results

obtained from the efflorescence test on the final brick products for the varying mix proportions can be explained using the following tabulated information in Table 4-20:

Table 4-20: Efflorescence test results for the final brick products

Mix proportions (clay % & GD %)	Mix number	Average efflorescence	Efflorescence grade
44 and 56	1	20.240	Moderate (up to 50%)
45 and 55	2	15.215	Moderate (up to 50%)
46 and 54	3	12.325	Moderate (up to 50%)
47 and 53	4	10.645	Slight (< 10%)
48 and 52	5	6.149	Slight (< 10%)
49 and 51	6	4.218	Slight (< 10%)
50 and 50	7	0.485	Slight (< 10%)
51 and 49	8	0.000	Nil (No perceptible deposit)
52 and 48	9	1.209	Slight (< 10%)
53 and 47	10	2.580	Slight (< 10%)
100 and 0	Control	3.075	Slight (< 10%)
$\text{Efflorescence percentage} = \frac{\text{Area of efflorescence}}{\text{Exposed area of brick sides}} \times 100\%$			

The final brick products having been cured for 28 days, these were subjected to the efflorescence test so as to determine if any soluble salts would be visible on the surfaces of these products. It was observed that the brick product made up of 51% clay and 49%

granite dust mix proportion had no visible soluble salts on its surface. This can be attributed to the lowering capillarity, as explained earlier on, which prevents migration from the inside of the brick to the outer surface. A higher affinity for water and loose fine particles with more porosity as the clay content in the brick increases also explains why salt deposits were observed on the surface of the other bricks beyond the already established optimum mix ratio.

#### 4.6.5. PARTICLE SIZE DISTRIBUTION OF THE MATERIAL FOR THE OPTIMAL MIX PROPORTION

Having used the compressive strength, water absorption capacity and efflorescence tests to establish the optimal mix ratio between clay and granite dust and the activator contents too, laboratory checks were done so as to establish the improvement of the

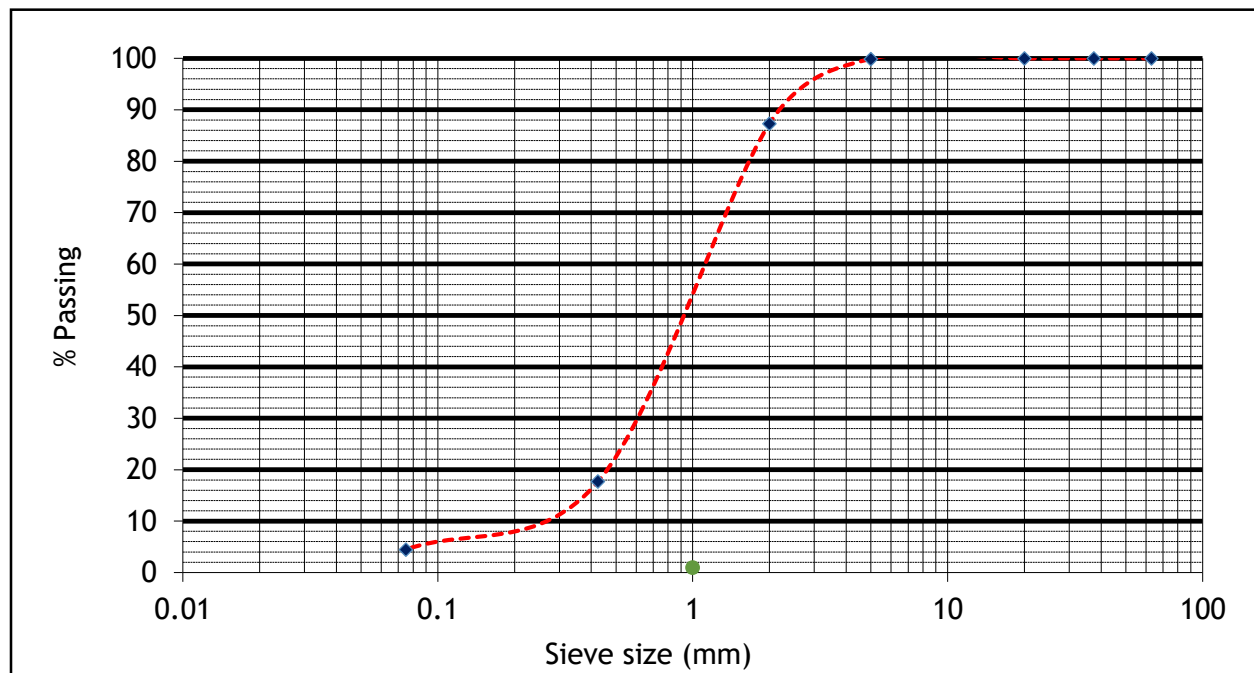


Figure 4-9: Grading curve of the clay soil sample and granite dust blend used for brick making

material for brick making by particle size. The grading envelope in Figure 4-9 was obtained for the test results obtained:

The grading envelope was covering most sections of the percentage passing hence showing it was well graded. This was however established using a grading modulus for the blended material between clay and the sodium silicate-activated granite dust and comparing the obtained result to the grading modulus criteria sourced from CALIFORNIA DEPARTMENT OF TRANSPORTATION (CAL TRANS) UNIFIED SOIL CLASSIFICATION SYSTEM UNIFIED SOIL CLASSIFICATION AND SYMBOL CHART.

$$\text{Grading mod.} = \frac{[300 - (\text{percentage passing on } 2\text{mm} + 0.425\text{mm} + 0.075\text{mm})]}{100} \quad \dots \text{Eqn. 5}$$

$$\text{Grading modulus} = \frac{[300 - (87.3 + 17.7 + 4.5)]}{100} = 1.905 \text{ (Well graded soil)} \quad \dots \text{Eqn. 6}$$

#### **4.6.6. ATTERBERG LIMITS OF THE MATERIAL FOR THE OPTIMAL MIX PROPORTION**

The test for the Atterberg limits was done in order to establish the new values for the liquid limit, plastic limit, shrinkage limit and most importantly the plasticity index of the final material for brick making.

The liquid limit was obtained as 34.7%, the plastic limit was 24.1% the shrinkage limit was 8.2% and the plasticity index was 10.6%. From the graph below, it can also be established that that the clay plasticity was lowered to make the material an inorganic clay with low plasticity.

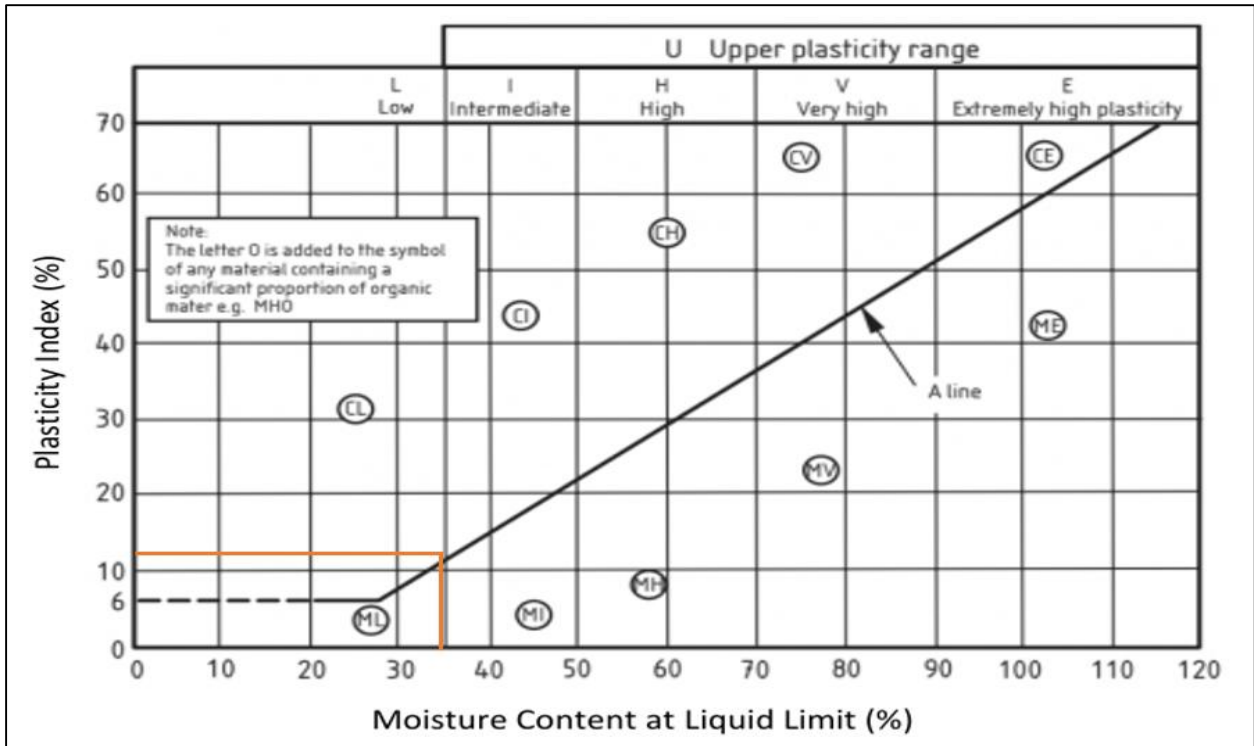


Figure 4-10: Atterberg limits results on a plasticity chart for the final brick making material (Sourced from BS 5930:2015)

The assessments above overall show that the characteristics of the final material for brick making allows for easy molding while also indicating the material has the ability to prevent uptake of excess water that usually causes swell or rapid drying and hence could prevent shrinkage cracking for the final brick product.

#### 4.6.7. CHEMICAL COMPOSITION OF THE MATERIAL FOR THE OPTIMAL MIX PROPORTION

In order to determine the final chemical composition of the material used for brick making, an XRF test was done so as to establish the chemical constituents. Comparison to the standards by chemical composition for a material suitable enough for brick

making was done so as to establish the suitability of the material formed. This assessment provided the results in Table 4-21:

Table 4-21: Suitability of the material for final brickmaking relative to the brickmaking standards by chemical composition

KEY ELEMENTS	% FROM XRF TEST	REQUIRED STANDARD (ASTM C618)	CLOSEST STANDARD	% DEV. $\frac{X - SD}{SD} \times 100$	% SUIT. $ 100 - \frac{\sum DEV}{ELTS} $
Silica	59.07%	50 to 60%	60%	18.14	<b>90.28%</b>
Alumina	29.61%	20 to 30%	30%	1.30	
Iron oxide	4.90%	Less than 7%	-	0.00	
Lime	2.30%	2 to 5%	-	0.00	
Magnesia	0.63%	Less than 1%	-	0.00	
Silica: Alumina	<b>2:1</b>				

By chemical composition, the material was 90.28% in match for a very good brickmaking material. Therefore, the final material comprising clay and the sodium silicate-activated granite dust was found to be suitable for brickmaking by chemical composition according to required standards for each chemical constituent. This result

can mainly be attributed to high silica content from granite dust and sodium silicate and alumina content from the granite dust alone which managed to boost the low available quantities in the initial clay material.

#### **4.6.8. LOAD BEARING CAPACITY OF THE BRICKS MANUFACTURED FROM MATERIAL FOR THE OPTIMAL MIX PROPORTION**

Here, the load bearing capacity test was done in order to determine the resistance of a short course wall or panel to shear force which was a combination of both vertical and lateral load (Borri, Castori and Corradi, 2014). This panel was comprised of 3 courses making the wall have a height of 228.6mm, thickness of 127.4mm and length 457.2mm (2 bricks in stretcher). The strength class of the mortar used in each case was M2.5 as per the standard, the results obtained from the assessments are as shown in Table 4-22.

From the assessment, it was established that the resistance to shear force was greater in the final brick product with the sodium silicate activated granite dust relative to its control. This can be attributed to the greater compressive strength of each masonry unit for the improved brick product. It was noted that according to BS 5628-1-1992, the shear resistance value was lying between 100kN and 150kN which implied that by recommendation, the improved brick product was suitable for both making walls on low cost buildings and suitable for non-load bearing walls on important structures.

Table 4-22: Results assessment from the load bearing capacity test

Element	Unfired clay brick panel made from clay and SS activated granite dust and mortar	Unfired clay brick panel with no additives and mortar
Brick compressive strength (Mpa)	4.92	1.98
Masonry compressive strength (MPa)	1.95	1.08
Wall area (mm <sup>2</sup> )	90820.8	90820.1
Eccentricity, e (mm)	21.2	21.2
Reduction factor $\Phi$	0.667	0.667
Load bearing capacity (KN)	118.1	65.4

## CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

### 5.1. CONCLUSION

This research project was aimed at assessing the suitability of manufacturing unfired clay bricks using sodium silicate-activated granite dust in Budondo sub-county. From the various laboratory tests carried out on the various materials and the analysis made, the following conclusions were drawn:

The initial clay material had 95.2% fine material and a plasticity index of 16.8%. Both values were above the required brickmaking standards of maximum 50% fine material and maximum 16% plasticity index according to the Green brickmaking manual. The fired brick from this clay soil gave brick compressive strength and water absorption capacity values of 2.3MPa and 19.5% while the unfired brick product gave 1.98MPa and 20.55% for the same parameters. Either result showed that there was need for improvement in the characteristics of the masonry units for better brick products since they did not achieve the minimum compressive strength of 5MPa and maximum water absorption capacity of 18% according to EN 1996-2:2006. The chemical composition of the clay itself was only 25.85% suitable for brick making.

Modifications to the soil were made using granite dust that had no fine material in addition to being non-plastic. The chemical composition of this material was 94.78% suitable for making a geopolymer and was activated by sodium silicate solution whose chemical composition also met the requirements of being capable to activate natural pozzolans since its silica to sodium ratio was 1.29 that lies within the required range of 1 to 3. Establishing an optimal mix ratio between the granite dust and the sodium

silicate was attained at a mix ratio of 9:1. The best blending ratio between the clay and granite dust was obtained at 51% and 49% respectively. The final brick product of from the clay and the sodium silicate-activated granite dust gave a compressive strength of 4.92MPa which was more than double the initial compressive strength. The water absorption capacity of the final brick product was also lowered to 13.75%. These values all met the required standards for bricks as masonry units. It was also established that the material formed from incorporating the sodium silicate-activated granite dust into clay for brick making had about 6% fines and a plasticity index of 10.6% which were both compliant with the standards for a suitable brick making material. Finally, a sustainable brick product was manufactured given the fact that only air drying was used as a technique for curing instead of sintering in a kiln.

## **5.2. RECOMMENDATIONS**

This research could be extended by academicians and students to determining other pozzolanic materials and or different methods that can be used for modifying the clay soil in Budondo sub-county for suitable brick making.

In addition, further research could be undertaken by brick manufacturers in Budondo sub-county so as to extend the study to determining the most efficient drying and curing techniques for the manufactured brick products so as to optimize brick strength development.

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**APPENDIX A: PHOTOS OF MATERIAL COLLECTION, PREPARATION AND TESTING**



Figure 1: Granite dust collection

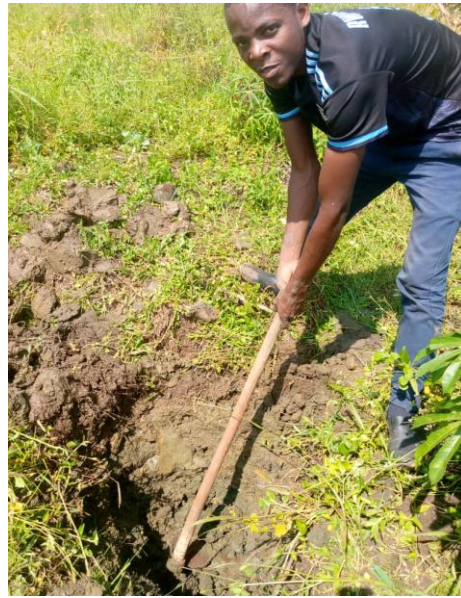


Figure 3: Soil sample collection



Figure 2: Sampling of the granite dust for cube



Figure 4: Particle size distribution test



Figure 6: Liquid limit test

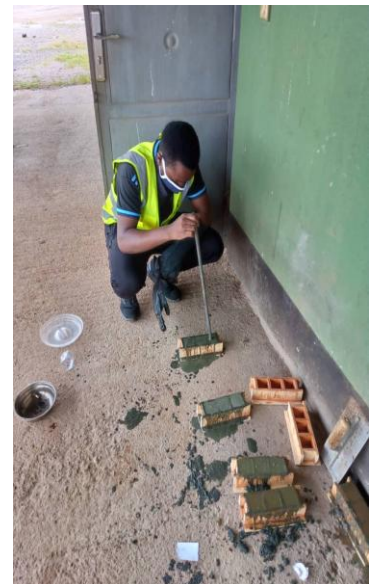


Figure 5: Casting of the geopolymer cubes



Figure 7: The geopolymer cubes after 28 days of air drying



Figure 8: Compressive strength test on the geopolymer cubes



Figure 9: Pre-crushing of the semi-dry clay material in preparation for brick making



Figure 10: Molding of the final brick product



Figure 11: Determining the weight of the final brick product



Figure 12: Final brick product after the water absorption capacity test


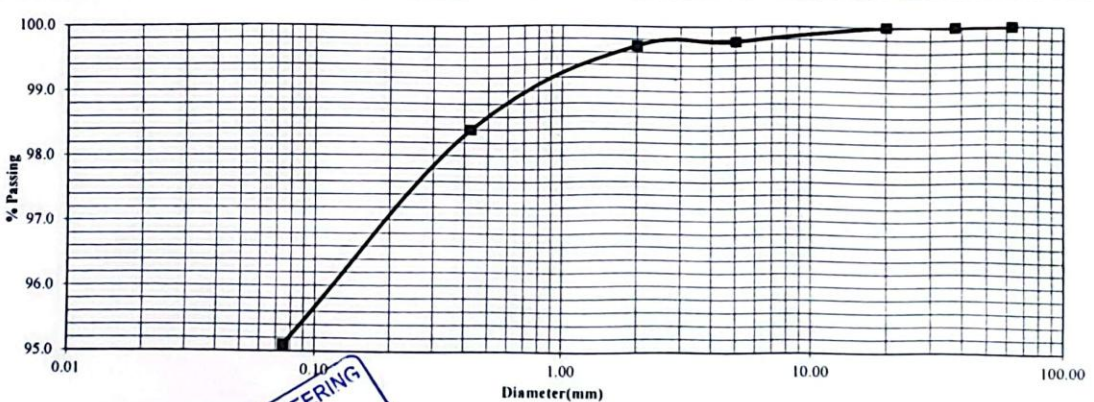




Figure 14: Compression strength test



Figure 13: Load bearing capacity test on the 3 course wall made of the final brick product

## APPENDIX B: PHOTOS OF ORIGINAL LABORATORY RESULTS

INSTITUTION	STUDENTS	TESTING LAB			
 <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A Centre of Excellence in the Heart of Africa</small>	<b>MWESIGE JOTHAM AND KAKANDE HANNINGTON</b>	<b>Stirling</b>			
<b>PROJECT :</b> <b>ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS</b>					
<b><u>PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)</u></b>					
<b>test reference no.</b>		Lab. Reference No.:			
Location :	Budondo subcounty trial pit	Dry wt. of sample before washing: (g)                      5154.6			
Depth: (m)	2.00	Dry wt. of sample after washing: (g)                      266.4			
Material description:	Unburnt clay brick making	Date Sampled:                      Date Tested:                      Technician			
		16/Dec/2024                      15/Jan/2025                      Lab team			
<b>Sieve Size (mm)</b>	<b>Weight Retained (g)</b>	<b>Retained (%)</b>	<b>Passing (%)</b>	<b>Grading Limits (G60 &amp; 80)</b>	
63.0	0.0	0.0	100.0		100
37.5	0.0	0.0	100.0	80	100
20.0	0.0	0.0	100.0	60	95
5.0	12.1	0.2	99.8	30	65
2.00	4.5	0.1	99.7	20	50
0.425	67.9	1.3	98.4	10	30
0.075	170.6	3.3	95.1	5	15
<b>Total fines</b>	4899.5	95.1			
<b>Bottom Pan</b>	11.3				
<b>Extracted fines</b>	4888.2				
<b>Total sample</b>	5154.6				
<b>Grading Modulus</b>		<b>0.07</b>			
					
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p><b>FOR TESTING LAB</b></p> <p>Lab Technician</p> </div> <div style="width: 45%; text-align: center;">  <p>Materials Engineer</p> </div> </div>					

<b>INSTITUTION</b>	<b>STUDENTS</b>	<b>TESTING LAB</b>
 <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A Centre of Excellence in the Heart of Africa</small>	<b>MWESIGE JOTHAM AND KAKANDE HANNINGTON</b>	<b>Stirling</b>

**PROJECT :** **ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS**

**PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)**

**test reference no.** \_\_\_\_\_ **Lab. Reference No.:** \_\_\_\_\_

**Location :** Budondo subcounty trial pit **Dry wt. of sample before washing: (g)** 4984.0

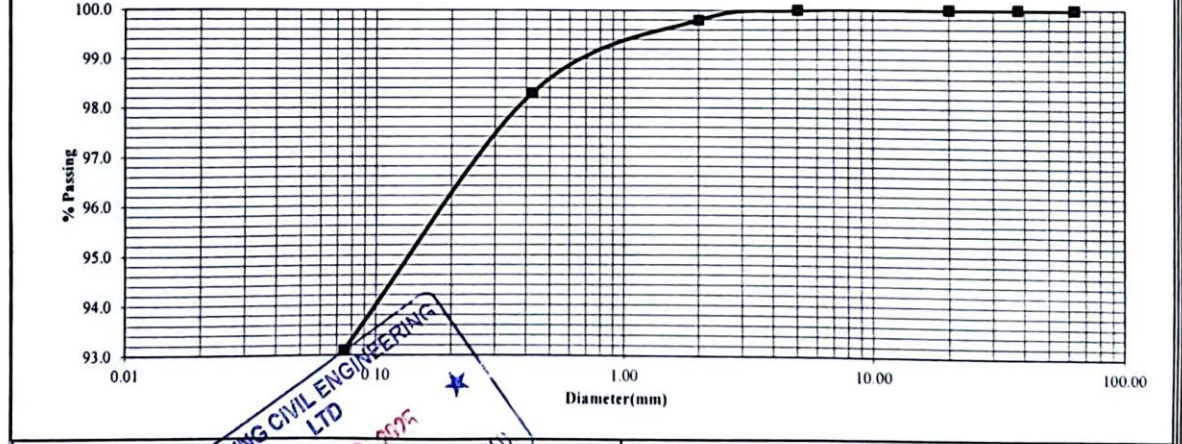
**Depth: (m)** 2.00 **Dry wt. of sample after washing: (g)** 333.9

**Material description:** Unburnt clay brick making

<b>Date Sampled:</b>	<b>Date Tested:</b>	<b>Technician</b>
16/Dec/2024	15/Jan/2025	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0.0	100.0		100
37.5	0.0	0.0	100.0	80	100
20.0	0.0	0.0	100.0	60	95
5.0	0.0	0.0	100.0	30	65
2.00	10.0	0.2	99.8	20	50
0.425	76.4	1.5	98.3	10	30
0.075	260.5	5.2	93.1	5	15
<b>Total fines</b>	4650.1	93.1			
<b>Bottom Pan</b>	12.9				
<b>Extracted fines</b>	4624.2				
<b>Total sample</b>	4984.0				


**Grading Modulus** 0.09



**FOR TESTING LAB**

Lab Technician \_\_\_\_\_ Materials Engineer \_\_\_\_\_



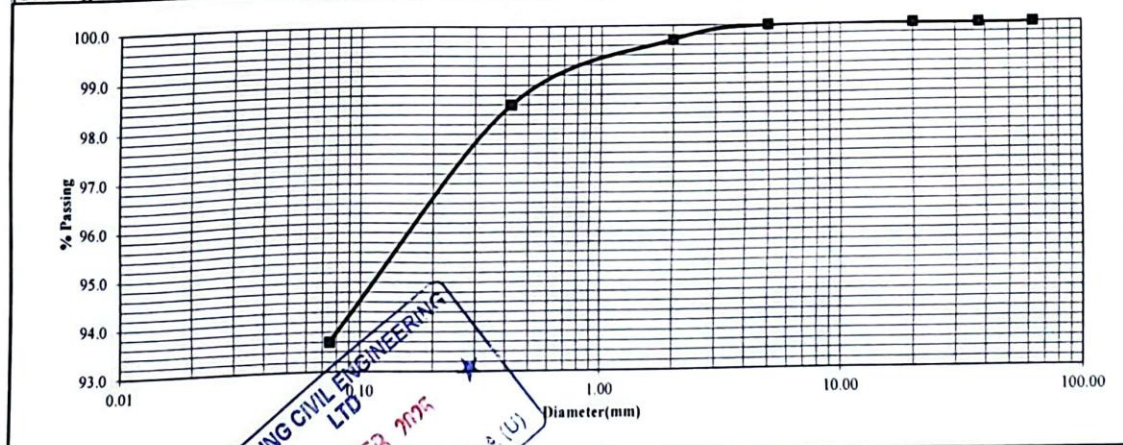
INSTITUTION	STUDENTS	TESTING LAB
 <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A Centre of Excellence in the Heart of Africa</small>	<b>MWESIGE JOTHAM AND KAKANDE HANNINGTON</b>	<b>Stirling</b>

**PROJECT :** **ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS**

**PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)**


<b>test reference no.</b>			Lab. Reference No.:		
Location :	Budondo subcounty trial pit		Dry wt. of sample before washing: (g)	5031.9	
Depth: (m)	2.00		Dry wt. of sample after washing: (g)	322.4	
Material description:	Unburnt clay brick making	Date Sampled:	Date Tested:	Technician	
		16/Dec/2024	15/Jan/2025	Lab team	
Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0.0	100.0		100
37.5	0.0	0.0	100.0	80	100
20.0	0.0	0.0	100.0	60	95
5.0	0.0	0.0	100.0	30	65
2.00	15.1	0.3	99.7	20	50
0.425	63.5	1.3	98.4	10	30
0.075	240.8	4.8	93.6	5	15
<b>Total fines</b>	4712.5	93.6			
<b>Bottom Pan</b>	13.0				
<b>Extracted fines</b>	4699.5				
<b>Total sample</b>	5031.9				


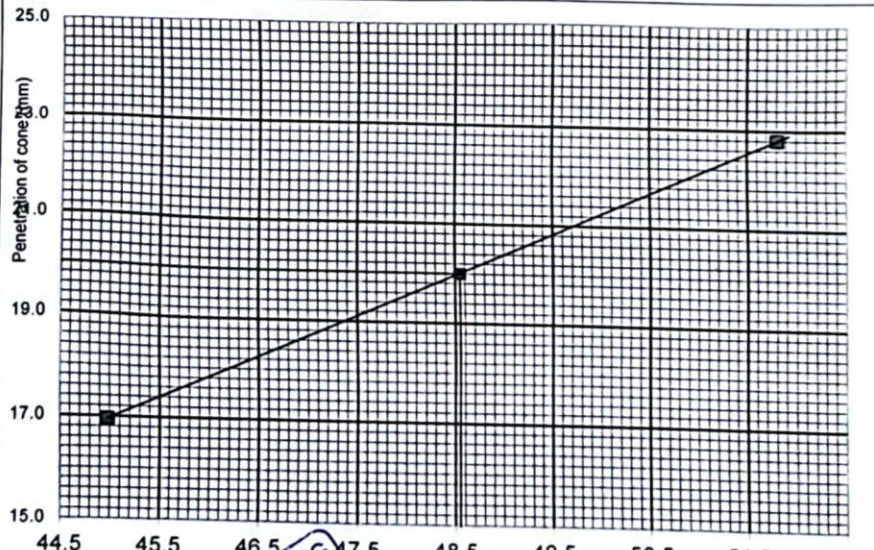
**Grading Modulus** 0.08



**FOR TESTING LAB**

Lab Technician: *[Signature]* Materials Engineer: *[Signature]*


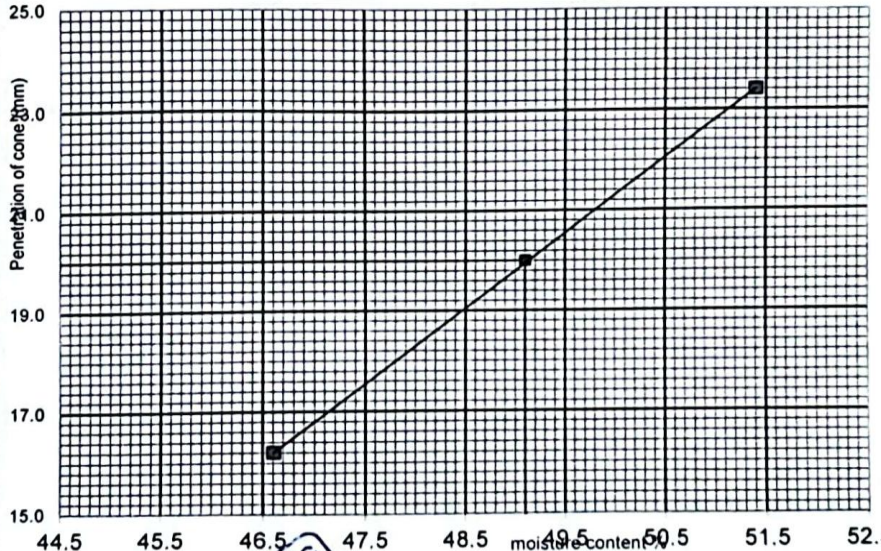

  
**STIRLING CIVIL ENGINEERING LTD**  
 11 FEB 2025  
 50X 798, KAMPALA (U)

INSTITUTION		CLIENT		CONTRACTOR							
 <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A Centre of Excellence in the Heart of Africa</small>		<b>MWESIGE JOTHAM AND KAKANDE HANNINGTON</b>		<div style="border: 2px solid black; border-radius: 10px; padding: 5px; display: inline-block;"> <b>Stirling</b> </div>							
PROJECT		<b>ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS</b>									
<b>ATTERBERG LIMITS BS 1377 PART 2:5:4-1990</b>											
Sample reference:				Sampling Date	16-Dec-24						
Location:	Budondo subcounty trial pit			Testing Date :	15-Jan-25						
Depth:				Technician :	JOINT TESTING						
sample description:	Clay soil for #RE51 brick making										
<b>CONE PENETRATION METHOD</b>											
LIQUID LIMIT		Liquid limit (%)				Plastic Limit (%)					
Test No		1	2	3	4						
Initial dail gauge reading	mm	0	0	0	0						
Final dail Gauge reading	mm	15.5	18.4	21.4	24.2						
Average penetration	mm	17.0		22.8							
Container No.		6E	PI600	BE	PI46	PIV6	PI38	PIQE	PI52		
Mass of wet soil +container	g	56.36	51.96	55.51	52.80	61.16	59.03	64.86	59.63	27.42	28.56
Mass of dry soil +container	g	46.91	34.10	46.06	34.08	48.16	37.28	51.86	37.18	26.03	27.17
Mass of container	g	7.18	7.11	6.94	7.14	6.95	7.10	7.07	7.18	21.65	22.84
Mass of moisture	g	9.5	17.9	9.5	18.7	13.0	21.8	13.0	22.5	1.4	1.4
Mass of dry soil	g	39.7	27.0	39.1	26.9	41.2	30.2	44.8	30.0	4.4	4.3
Moisture content	%	23.8	66.2	24.2	69.5	31.5	72.1	29.0	74.8	31.7	32.1
Average Moisture content	%	45.0		46.8		51.8		51.9		31.9	
		Liquid limit%		48.6							
		Plastic Limit %		31.9							
		Plasticity Index %		16.7							
		Reference:									
Initial length $L_0$ (mm)	14	14	Shrinkage								
Oven dried length $L_d$ (mm)	12.7	12.5									
Linear shrinkage $\frac{L_0 - L_d}{L_0} \times 100$ (%)	9.3	10.7	10.0								
For contractor			For consultant								

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INSTITUTION		CLIENT		CONTRACTOR		
 <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A Centre of Excellence in the Heart of Africa</small>		<b>MWESIGE JOTHAM AND KAKANDE HANNINGTON</b>		<div style="border: 2px solid black; border-radius: 10px; padding: 5px; display: inline-block;"> <b>Stirling</b> </div>		
<b>PROJECT</b>		<b>ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS</b>				
<b>ATTERBERG LIMITS BS 1377 PART 2:4-1990</b>						
Sample reference:				Sampling Date	16-Dec-24	
Location:	Budondo subcounty trial pit			Testing Date :	15-Jan-25	
Depth:				Technician :	JOINT TESTING	
sample description:	#REF! Clay soil for brick making					
<b>CONE PENETRATION METHOD</b>						
		Liquid limit (%)				Plastic Limit (%)
<b>LIQUID LIMIT</b>	Test No	1	2	3	4	
Initial dial gauge reading	mm	0	0	0	0	
Final dial Gauge reading	mm	16.1	16.3	23.3	23.5	
Average penetration	mm	16.2			23.4	
Container No.		BAH	F05	ZX	BM	PI5
Mass of wet soil +container	g	51.58	54.39	60.00	62.63	24.46
Mass of dry soil +container	g	42.13	43.37	47.44	48.43	23.07
Mass of container	g	21.85	19.73	23.16	20.75	18.77
Mass of moisture	g	9.5	11.0	12.6	14.2	1.4
Mass of dry soil	g	20.3	23.6	24.3	27.7	4.3
Moisture content	%	46.6	46.6	51.3	51.5	32.3
Average Moisture content	%	46.6			51.4	32.3
Penetration of cone (mm) 		Liquid limit% <b>49.1</b>				
		Plastic Limit % <b>32.3</b>				
		Plasticity Index % <b>16.8</b>				
		Reference:				
<b>LINEAR SHRINKAGE</b>		1	2	Average Shrinkage		
Initial length Lo (mm)		14	14	<b>10.4</b>		
Oven dried length Ld (mm)		12.6	12.5			
Linear shrinkage $100 \times (1 - Ld/Lo)$ (%)		10.0	10.7			
For contractor		For consultant				

STIRLING ENGINEERING

No. 50K 798, Kampala, Uganda

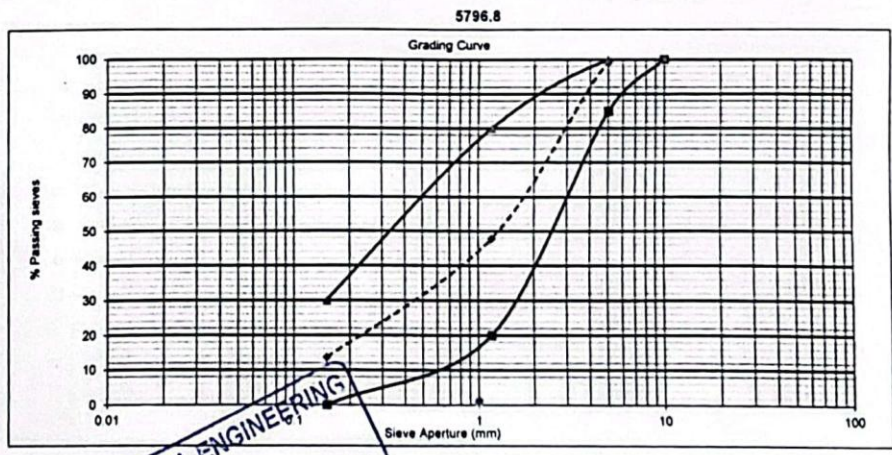
2025

INSTITUTION  <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A Centre of Excellence in the Heart of Africa</small>	CLIENT <b>MWESIGE JOTHAM AND KAKANDE HANNINGTON</b>	TESTING LAB <div style="border: 2px solid black; padding: 5px; display: inline-block; margin: 10px 0;"> <b>Stirling</b> </div> <small>Stirling Civil Engineering Ltd</small>
<b>STIRLING MUKONO LABORATORY</b>		


**PROJECT      ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS**

<b>GRADING FOR AGGREGATES</b>	
(BS)	
LOCATION: <u>Budondo subcounty</u> SUPPLIER: <u>MM quarry factory</u> SAMPLE No: _____ MATERIAL DESCRIPTION: <u>GRANITE QUARRY DUST</u>	OPERATORS: _____ TOTAL DRY WT. OF SAMPLE: <u>5796.8</u> TOTAL DRY WT. OF SAMPLE AFTER: <u>5479.4</u> SAMPLE DATE: _____ DATE SAMPLED: <u>14/12/2024</u> DATE TESTED: <u>15/01/2025</u>

MAXIMUM SIEVE SIZE (mm)	WEIGHT RETAINED (gm)	PERCENTAGE RETAINED (%)	PERCENTAGE PASSING (%)	SPECIFIED LIMITS (spec table 4502/1) (%)
10.0	0	0.0	100.0	100
5.000	45	0.8	99.2	85 - 100
1.180	2983.7	51.5	47.8	20 - 80
0.150	1977.7	34.1	13.6	0 - 30
PAN	463			
WEIGHT LOST DURING SIEVING	327.4			
<b>TOTAL</b>	<b>5796.8</b>			



  
**STIRLING CIVIL ENGINEERING LTD**  
 15/01/2025  
 For Testing Lab  
 P.O. Box 796, KAMPALA (U)

INSTITUTION	CLIENT	TESTING LAB
 <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A Centre of Excellence in the Heart of Africa</small>	<b>MWESIGE JOTHAM AND KAKANDE HANNINGTON</b>	<div style="border: 1px solid black; padding: 5px; display: inline-block;"><b>Stirling</b></div> <small>Stirling Civil Engineering Ltd</small>
<b>STIRLING MUKONO LABORATORY</b>		

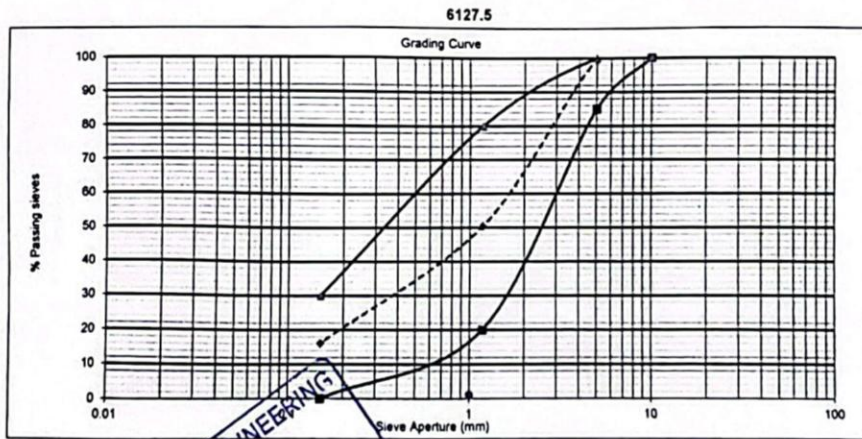
PROJECT **ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS**

**GRADING FOR AGGREGATES**


(BS)

LOCATION: <u>Budondo subcounty</u> SUPPLIER: <u>MM quarry factory</u> SAMPLE No: _____ MATERIAL DESCRIPTION: <u>GRANITE QUARRY DUST</u>	OPERATORS: _____ TOTAL DRY WT. OF SAMPLE: <u>6127.5</u> TOTAL DRY WT. OF SAMPLE AFTER: <u>5414.9</u> SAMPLE DATE: _____ DATE SAMPLED: <u>14/12/2024</u> DATE TESTED: <u>15/01/2025</u>
--	---

MAXIMUM SIEVE SIZE (mm)	WEIGHT RETAINED (gm)	PERCENTAGE RETAINED (%)	PERCENTAGE PASSING (%)	SPECIFIED LIMITS (spec table 4502/1) (%)
10.0	0	0.0	100.0	100
5.000	28.1	0.5	99.5	85 - 100
1.180	3010.8	49.1	50.4	20 - 80
0.150	2102.8	34.3	16.1	0 - 30
PAN	278.4			
WEIGHT LOST DURING SIEVING	707.4			
<b>TOTAL</b>	<b>6127.5</b>			



  
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INSTITUTION	CLIENT	TESTING LAB
 <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A Centre of Excellence in the Heart of Africa</small>	<b>MWESIGE JOTHAM AND KAKANDE HANNINGTON</b>	<div style="border: 1px solid black; padding: 5px; display: inline-block;"> <b>Stirling</b> </div> <small>Stirling Civil Engineering Ltd</small>
<b>STIRLING MUKONO LABORATORY</b>		

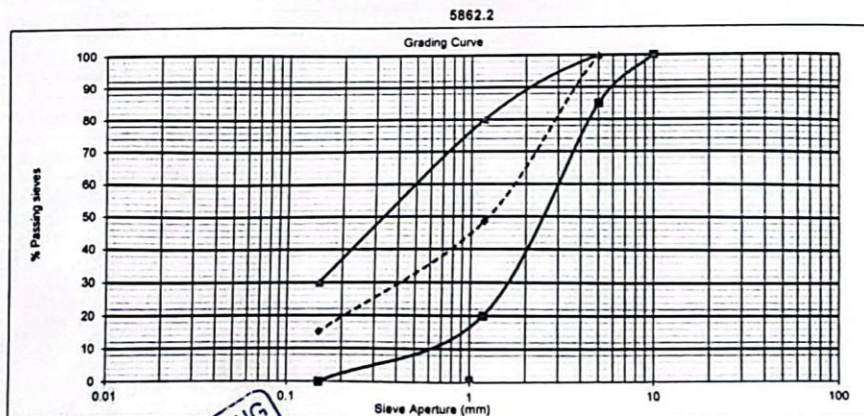
PROJECT: **ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS**


**GRADING FOR AGGREGATES**

(BS)

LOCATION: <u>Budondo subcounty</u> SUPPLIER: <u>MM quarry factory</u> SAMPLE No: _____ MATERIAL DESCRIPTION: <u>GRANITE QUARRY DUST</u>	OPERATORS: _____ TOTAL DRY WT. OF SAMPLE: <u>5862.2</u> TOTAL DRY WT. OF SAMPLE AFTER: <u>5375.6</u> SAMPLE DATE: _____ DATE SAMPLED: <u>14/12/2024</u> DATE TESTED: <u>15/01/2025</u>
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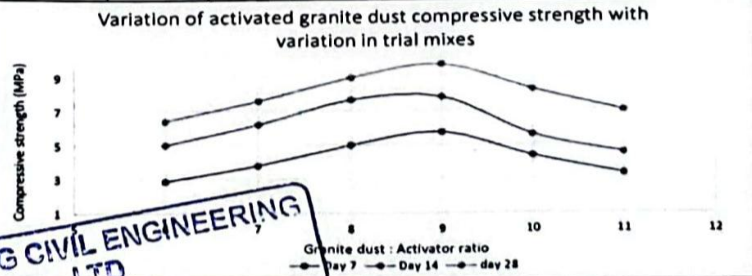
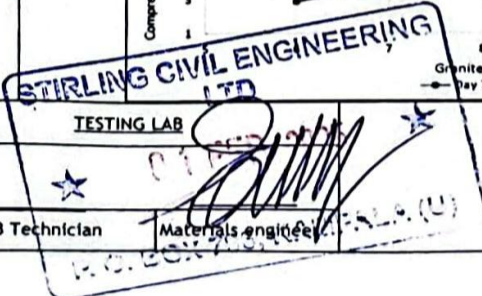

MAXIMUM SIEVE SIZE (mm)	WEIGHT RETAINED (gm)	PERCENTAGE RETAINED (%)	AVERAGE OF 2 PERCENTAGE PASSING (%)	SPECIFIED LIMITS (spec table 4502/1) (%)
10.0	0	0.0	100.0	100
5.000	25.7	0.4	99.6	85 - 100
1.180	2994.6	51.1	48.5	20 - 80
0.150	1959.2	33.4	15.1	0 - 30
PAN	396.1			
WEIGHT LOST DURING SIEVING	486.6			
<b>TOTAL</b>	<b>5862.2</b>			



INSTITUTION		CLIENT				CONTRACTOR			
 <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A Centre of Excellence in the Heart of Africa</small>		MWESIGE JOTHAM AND KAKANDE HANNINGTON				<b>Stirling</b>			
PROJECT	FINAL YEAR RESEARCH AND DESIGN PROJECT								
Procurement no.									
Test	Water absorption test							Cast date:	21/Dec/2024
Location	Budondo Sub county							Test date:	18/Jan/2025
sample description	Sodium silicate activated granite dust mortar cubes for bricks making							Age (days)	28
Mass of material used per cube (g):	500							Temperature(°C)	24
							Density of water	1000 Kg/m <sup>3</sup>	
Trial mix	Cube dimension (mm)	Oven dried weight (g)	SSD weight (g)	Weight under water (g)	bulk density (kg/m <sup>3</sup> )	Water absorption (%)	Avg bulk density (kg/m <sup>3</sup> )	Average water absorption (%)	Granite dust : activator ratio
1	49.9x50.1x50.3	294.1	311.7	201.1	2.7	6.0	2.7	5.8	6
	50.1x50.0x50.2	293.8	310.6	204.3	2.8	5.7			
	50.0x50.4x50.2	294.4	311.5	204.6	2.8	5.8			
2	50.3x50.3x50.1	295.4	308.2	202.3	2.8	4.3	2.8	4.3	7
	50.2x49.8x49.9	294.9	307.9	201.8	2.8	4.4			
	50.3x50.1x50.2	295.2	307.6	200.5	2.8	4.2			
3	50.0x50.0x50.1	295.7	306.5	201.7	2.8	3.7	2.8	3.7	8
	50.1x50.4x50.2	295.8	306.4	201.2	2.8	3.6			
	50.3x50.0x50.1	295.3	306.8	201.1	2.8	3.9			
4	50.1x49.8x50.0	297.5	304.3	185.3	2.5	2.3	2.5	2.4	9
	50.0x50.1x50.0	297.1	304.7	185.7	2.5	2.6			
	50.2x50.1x50.3	297.7	304.7	185.8	2.5	2.4			
5	50.4x50.2x49.9	296.6	310.4	192.4	2.5	4.7	2.5	4.7	10
	50.2x50.0x50.3	296.1	310.9	192.7	2.5	5.0			
	50.1x49.7x50.4	296.9	310.1	192.3	2.5	4.4			
6	50.0x50.1x50.1	293.9	313.9	201.3	2.6	6.8	2.6	6.8	11
	51.2x50.4x50.0	293.7	314	201.5	2.6	6.9			
	50.1x50.2x50.3	294.1	313.6	201	2.6	6.6			

  
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					bulk density (kg/m <sup>3</sup> )	2.7														
<b>WATER ABSORPTION OF SODIUM SILICATE ACTIVATED GRANITE DUST</b>																				
<table border="1" style="margin: 10px auto;"> <caption>Data points from the graph</caption> <thead> <tr> <th>Granite Dust : Activator Ratio</th> <th>Water Absorption (%)</th> </tr> </thead> <tbody> <tr><td>6</td><td>5.8</td></tr> <tr><td>7</td><td>4.3</td></tr> <tr><td>8</td><td>3.7</td></tr> <tr><td>9</td><td>2.4</td></tr> <tr><td>10</td><td>4.7</td></tr> <tr><td>11</td><td>6.8</td></tr> </tbody> </table>							Granite Dust : Activator Ratio	Water Absorption (%)	6	5.8	7	4.3	8	3.7	9	2.4	10	4.7	11	6.8
Granite Dust : Activator Ratio	Water Absorption (%)																			
6	5.8																			
7	4.3																			
8	3.7																			
9	2.4																			
10	4.7																			
11	6.8																			
			CLIENT																	
					MWESIGE JOTHAM		KAKANDE HANNINGTON													

INSTITUTION		CLIENT				TESTING LAB					
 <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A College of Excellence in the Heart of Africa</small>		<b>MWESIGE JOTHAM AND KAKANDE HANNINGTON</b>				<div style="border: 1px solid black; border-radius: 15px; padding: 5px; display: inline-block;">Stirling</div>					
<b>PROJECT</b>		<b>ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS</b>									
<b>Test</b>		Determination of the compressive strength of pozzolan cement mortar cubes									
<b>Location</b>		Granite dust from MM stone quarry in Budondo sub county in Jinja district									
<b>Structure</b>		Geopolymer mortars to be used for the manufacture of unburnt clay bricks									
<b>Sodium silicate : Sodium hydroxide : Water</b>		2.5 : 1 : 0.4									
Trial mix	Casting date	Testing date	Cube dimension (mm)	Weight (kg)	Density (kg/m <sup>3</sup> )	Age (days)	Crushing load (kN)	Compressive strength (MPa)	Average strength (MPa)	Granite dust/ activator ratio	
1	21-Dec-24	28-Dec-24	50x50x50	0.3	2400	7	7.1	2.84	2.86	6	
			50x50x50	0.29	2320		7.2	2.88			
	21-Dec-24	04-Jan-25	50x50x50	0.3	2400	14	12.5	4.99	5.01		
			50x50x50	0.27	2160		12.6	5.03			
	21-Dec-24	18-Jan-25	18-Jan-25	50x50x50	0.3	2400	28	15.7	6.26		6.41
				50x50x50	0.28	2240		16.4	6.56		
2	21-Dec-24	28-Dec-24	50x50x50	0.3	2400	7	9.4	3.74	3.78	7	
			50x50x50	0.29	2320		9.6	3.82			
	21-Dec-24	04-Jan-25	50x50x50	0.28	2240	14	14.9	5.97	6.19		
			50x50x50	0.3	2400		16	6.41			
	21-Dec-24	18-Jan-25	18-Jan-25	50x50x50	0.3	2400	28	18.7	7.47		7.58
				50x50x50	0.29	2320		19.2	7.69		
3	21-Dec-24	28-Dec-24	50x50x50	0.3	2400	7	12.3	4.91	4.99	8	
			50x50x50	0.3	2400		12.7	5.07			
	21-Dec-24	04-Jan-25	50x50x50	0.27	2160	14	19.1	7.63	7.64		
			50x50x50	0.29	2320		19.1	7.65			
	21-Dec-24	18-Jan-25	18-Jan-25	50x50x50	0.3	2400	28	22.3	8.92		8.96
				50x50x50	0.3	2400		22.5	9		
4	21-Dec-24	28-Dec-24	50x50x50	0.3	2400	7	14.3	5.71	5.74	9	
			50x50x50	0.29	2320		14.4	5.77			
	21-Dec-24	04-Jan-25	50x50x50	0.28	2240	14	19.7	7.86	7.81		
			50x50x50	0.27	2160		19.4	7.76			
	21-Dec-24	18-Jan-25	18-Jan-25	50x50x50	0.3	2400	28	24.4	9.77		9.74
				50x50x50	0.3	2400		24.4	9.71		
5	21-Dec-24	28-Dec-24	50x50x50	0.3	2400	7	10.6	4.25	4.34	10	
			50x50x50	0.27	2160		11.1	4.43			
	21-Dec-24	04-Jan-25	50x50x50	0.27	2160	14	14	5.61	5.57		
			50x50x50	0.29	2320		13.8	5.53			
	21-Dec-24	18-Jan-25	18-Jan-25	50x50x50	0.3	2400	28	20.7	8.29		8.24
				50x50x50	0.3	2400		20.5	8.19		
6	21-Dec-24	28-Dec-24	50x50x50	0.28	2240	7	8.2	3.26	3.29	11	
			50x50x50	0.27	2160		8.3	3.32			
	21-Dec-24	04-Jan-25	50x50x50	0.3	2400	14	11.3	4.53	4.51		
			50x50x50	0.3	2400		11.2	4.49			
	21-Dec-24	18-Jan-25	18-Jan-25	50x50x50	0.28	2240	28	17.6	7.05		6.97
				50x50x50	0.3	2400		17.2	6.89		
<b>Variation of activated granite dust compressive strength with variation in trial mixes</b>											
											
TESTING LAB						CLIENT:					
											
LAB Technician			Materials engineer			Mwesige Jotham		Kakande Hannington			

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 +256 (0) 414 250 474  
 Email: dgal@mla.go.ug  
 Website: www.mla.go.ug



**MINISTRY OF INTERNAL AFFAIRS**  
**DIRECTORATE OF GOVERNMENT**  
**ANALYTICAL LABORATORY**  
 Plot No. 2 Lourdel Road  
 Wandegaya,  
 P.O. Box 105639  
 Kampala - Uganda

In any Correspondence on  
 this subject please  
 quote No.....

**DFD 015/2025**  
**29<sup>th</sup> January 2025**

MR. MWESIGYE JOTHAM AND MR. KAKANDE HANNINGTON  
 REG NO. S20B32/009 & S21B33/069  
 UGANDA CHRISTIAN UNIVERSITY  
 P.O BOX 4,  
 MUKONO-UGANDA  
 Tel: 256-780-314873

### REPORT OF ANALYSIS

#### Description of the Samples

One sample in black polythene bag containing Brown soil sample was submitted by Mr. Kakande Hannington, on 20<sup>th</sup> January 2025, and analysed on 24<sup>th</sup> January 2025. A summary of the sample received is shown in table below

S/N	Description	Quantity	Assigned Lab ID
1	Brown powdered substances packed in a black polythene bag.	01	Sample "B" DFD 015/2025

#### Analysis Requested

Elemental analysis

#### Method of Analysis

Elemental analysis was done using the XRF Method while Moisture and loss on ignition were done using the thermogravimetric method.

#### Results of Analysis

The above sample has been analyzed with the following results as below.

Parameter	Units	Results for DFD 015/2025 Brown soil sample
Loss on Ignition	% m/m	6.713
Moisture	% m/m	29.091
<b>Elemental Composition</b>		
Silicon dioxide	% m/m	10.834
Calcium oxide	% m/m	7.070
Potassium Oxide	% m/m	6.396
Titanium dioxide	% m/m	9.302
Sodium Oxide	% m/m	8.123
Iron (III) Oxide	% m/m	10.201
Aluminium oxide	% m/m	5.705
Magnesium (II) Oxide	% m/m	4.923
Phosphorous pent oxide	% m/m	1.546

#### Remarks

- Results relate to sample analyzed and are reported as on received basis.

*Semalago Fredrick* 29/01/25

Semalago Fredrick  
 Government Analyst

"Go Scientific for a Safe and Just Society"

Telephone  
 +256 (0) 414 250 464 (Gen)  
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In any Correspondence on  
 this subject please  
 quote No.....



**MINISTRY OF INTERNAL AFFAIRS**  
**DIRECTORATE OF GOVERNMENT**  
**ANALYTICAL LABORATORY**  
 Plot No. 2 Lourdel Road  
 Wandegaya,  
 P.O. Box 105639  
 Kampala - Uganda

**DFD 014/2025**

**29<sup>th</sup> January 2025**

MR. MWESIGYE JOTHAM AND MR. KAKANDE HANNINGTON  
 REG NO. S20B32/009 & S21B33/069  
 UGANDA CHRISTIAN UNIVERSITY  
 P.O BOX 4,  
 MUKONO-UGANDA  
 Tel: 256-780-314873

**REPORT OF ANALYSIS**

**Description of the Samples**

One sample in black polythene bag containing Granite powder sample was submitted by Mr. Kakande Hannington, on 20<sup>th</sup> January 2025, and analysed on 24<sup>th</sup> January 2025. A summary of the sample received is shown in table below

S/N	Description	Quantity	Assigned Lab ID
1	Fine gritty aggregates packed in a black polythene bag.	01	Sample "A" DFD 014/2025

**Analysis Requested**

Elemental analysis

**Method of Analysis**

Elemental analysis was done using the XRF Method while loss on ignition was done using the thermogravimetric method.

**Results of Analysis**

The above sample has been analyzed with the following results as below.

Parameter	Units	Results for DFD 014/2025 Granite Powder
Loss on Ignition	% m/m	0.038
<b>Elemental Composition</b>		
Silicon dioxide	% m/m	72.301
Aluminium oxide	% m/m	14.653
Calcium oxide	% m/m	1.863
Potassium Oxide	% m/m	4.447
Iron (III) Oxide	% m/m	1.732
Manganese (II) Oxide	% m/m	0.474
Phosphorous pent oxide	% m/m	0.297
Sodium Oxide	% m/m	3.121
Titanium dioxide	% m/m	1.100

**Remarks**

1. Results relate to sample analyzed and are reported as on received basis.

*Semalago Fredrick*  
 Semalago Fredrick  
 Government Analyst

*"Go Scientific for a Safe and Just Society"*

**MAKERERE**

P.O. BOX 7062, Kampala, Uganda  
Email: geology@cns.mak.ac.ug  
Website: http://geology.mak.ac.ug/



**UNIVERSITY**

Tel: + 256 - 414 - 541258  
Fax: + 256 - 414 - 531061

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

Monday, 10 February 2025

Kakande Hannington and Mwesige J.  
UCU Students

Dear Sir/Madam,

**RE: ANALYSIS OF SODIUM SILICATE SAMPLE**




The Department received one sample to be analysed for Si and Na. During analysis the sample was scanned using an XRF spectrometer (Epsilon 1) for Si determination. While sodium was determined by diluting the sample appropriately, and aspirating it directly on the atomic absorption spectrophotometer (Agilent 240FS AA). The results below expressed in grams per litre (g/l) were obtained.




Sample No	Si (g/l)	Na (g/l)
Sodium silicate sample	98.8	76.4
<u>Detection Limit</u>	<u>0.01</u>	<u>0.01</u>




Analyst: 



**KASAKA MOSES**



**Geochemistry Laboratory**



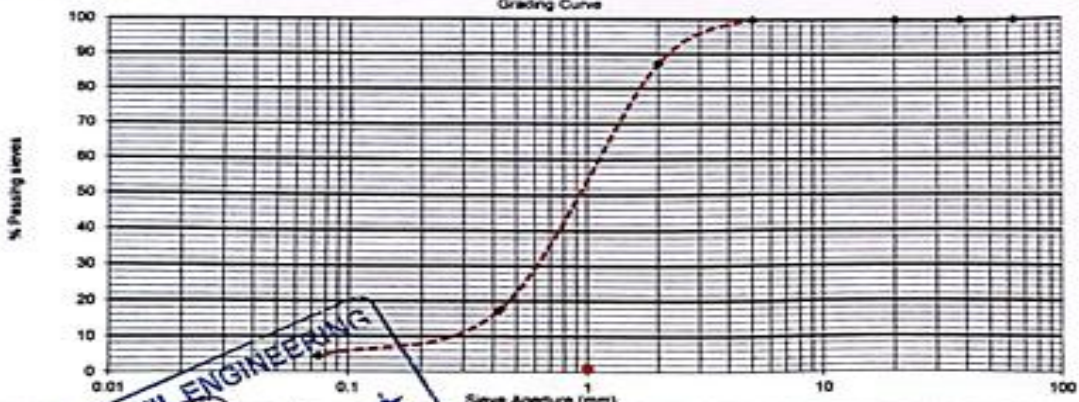
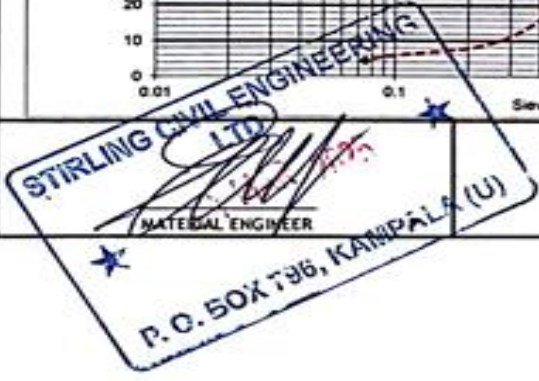
INSTITUTION			CLIENT			LABORATORY		
 <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A Centre of Excellence in the Heart of Africa</small>			<b>MWESIGE JOTHAM</b> <b>KAKANDE HANNINGTON</b>					
PROJECT			ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS					
Location			Budondo sub-county Jinja District					
Test			Determination of the compressive strength of unfired clay bricks					
Material description			Unfired clay bricks made from blending sodium silicate-activated granite dust and clay					
Molding date			4/Feb/2025					
Testing date			5/Mar/2025					
Age			7 days					
Clay % & GD %	Mix no.	Label	Dimension (mm)	Weight (kg)	Density (kg/m <sup>3</sup> )	Crushing load (kN)	Compressive strength (MPa)	Avg. (MPa)
100 and 0	Control	CS1	228.4X127.0X76.0	3.571	1506.51	34.81	1.20	1.20
		CS2	228.5X127.0X75.9	3.572	1508.92	31.92	1.10	
44 and 56	1	A1	228.5X127.0X76.1	3.678	1531.66	73.42	2.53	2.43
		A2	228.3X126.9X75.9	3.677	1533.78	68.20	2.35	
45 and 55	2	B1	228.5X126.7X75.6	3.711	1559.27	70.23	2.42	2.45
		B2	228.2X126.8X75.7	3.703	1547.67	71.97	2.48	
46 and 54	3	C1	228.5X126.6X76.1	3.718	1583.79	70.23	2.42	2.45
		C2	228.4X126.6X76.0	3.737	1579.32	71.97	2.48	
47 and 53	4	D1	228.3X126.8X75.8	3.733	1609.93	74.87	2.58	2.60
		D2	228.6X126.7X75.9	3.754	1611.73	73.13	2.52	
48 and 52	5	E1	228.1X126.5X75.7	3.747	1635.07	75.16	2.59	2.64
		E2	228.3X126.8X75.6	3.748	1636.88	77.77	2.68	
49 and 51	6	F1	228.5X126.7X75.7	3.796	1661.09	77.48	2.67	2.67
		F2	228.4X126.6X76.0	3.798	1660.45	77.48	2.67	
50 and 50	7	G1	228.3X126.6X75.5	3.799	1685.80	77.77	2.68	2.68
		G2	228.4X126.6X75.7	3.797	1691.59	77.77	2.68	
51 and 49	8	H1	228.5X126.7X75.8	3.891	1737.52	87.35	3.01	2.98
		H2	228.6X126.9X75.9	3.842	1736.67	114.63	3.95	
52 and 48	9	L1	228.2X126.5X75.7	3.847	1714.80	80.96	2.79	2.76
		L2	228.3X126.9X75.6	3.856	1717.46	78.93	2.72	
53 and 47	10	I1	228.4X126.7X75.8	3.839	1692.78	77.48	2.67	2.65
		J2	228.5X126.6X75.5	3.859	1693.16	76.03	2.62	
					Students			
					Mwesige Jotham		Kakande Hannington	


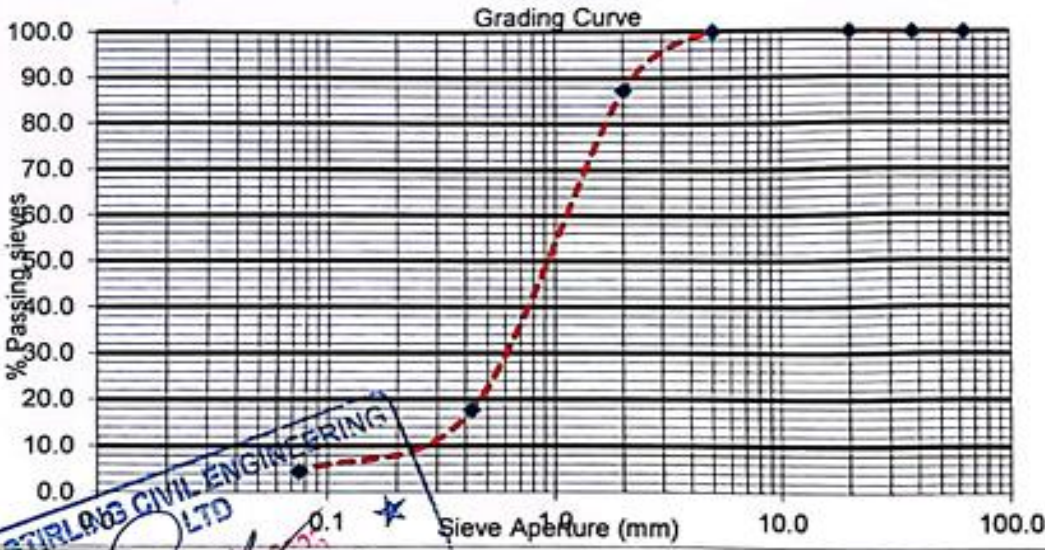
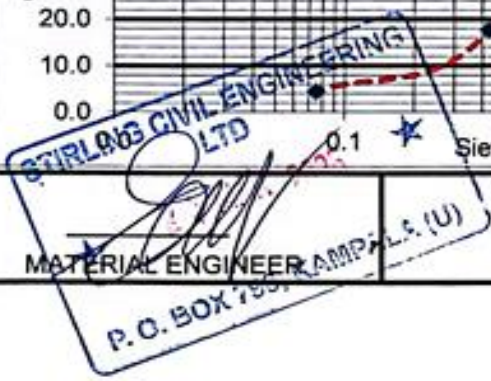
INSTITUTION		CLIENT				LABORATORY			
 <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A Centre of Excellence in the Heart of Africa</small>		<b>MWESIGE JOTHAM</b> <b>KAKANDE HANNINGTON</b>							
<b>PROJECT</b>		ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS							
<b>Location</b>		Budondo sub-county Jinja District							
<b>Test</b>		Determination of the compressive strength of unfired clay bricks							
<b>Material description</b>		Unfired clay bricks made from blending sodium silicate-activated granite dust and clay							
<b>Molding date</b>				4/Feb/2025					
<b>Testing date</b>				5/Mar/2025					
<b>Age</b>				14 days					
Clay % & GD %	Mix no.	Label	Dimension (mm)	Weight (kg)	Density (kg/m <sup>3</sup> )	Crushing load (kN)	Compressive strength (MPa)	Avg. (MPa)	
100 and 0	Control	CS1	228.2X127.0X75.9	3.557	1617.05	46.66	1.61	1.42	
		CS2	228.3X127.1X76.1	3.563	1613.54	35.40	1.22		
44 and 56	1	A1	228.3X126.9X76.0	3.662	1663.17	86.04	2.97	2.81	
		A2	228.5X126.9X76.0	3.669	1664.89	76.84	2.65		
45 and 55	2	B1	228.4X126.8X76.1	3.704	1680.63	77.04	2.66	2.86	
		B2	228.6X126.8X76.2	3.695	1672.88	86.67	2.99		
46 and 54	3	C1	228.3X126.8X75.8	3.71	1690.75	86.85	3.00	2.99	
		C2	228.4X126.9X75.9	3.728	1694.64	86.08	2.97		
47 and 53	4	D1	228.6X127.0X76.1	3.729	1690.04	93.48	3.22	3.25	
		D2	228.3X126.9X75.9	3.741	1701.29	95.03	3.28		
48 and 52	5	E1	228.4X126.8X76.1	3.739	1696.51	93.54	3.23	3.34	
		E2	228.5X126.7X75.8	3.733	1701.08	99.88	3.45		
49 and 51	6	F1	228.3X126.9X75.9	3.741	1701.29	108.93	3.76	3.87	
		F2	228.4X126.9X75.8	3.796	1727.82	115.07	3.97		
50 and 50	7	G1	228.5X126.8X75.6	3.798	1733.91	112.13	3.87	3.92	
		G2	228.6X126.5X75.5	3.791	1736.36	114.80	3.97		
51 and 49	8	H1	228.2X126.5X75.6	3.891	1782.93	126.15	4.37	4.27	
		H2	228.3X126.8X75.8	3.992	1819.27	121.87	4.21		
52 and 48	9	L1	228.5X126.9X76.0	3.998	1814.18	102.94	3.55	3.77	
		L2	228.5X126.8X75.9	3.986	1812.55	115.32	3.98		
53 and 47		J1	228.4X126.9X76.1	3.989	1808.51	100.86	3.48	3.63	
		J2	228.6X126.8X75.8	3.980	1811.42	109.57	3.78		
					<u>Students</u>				


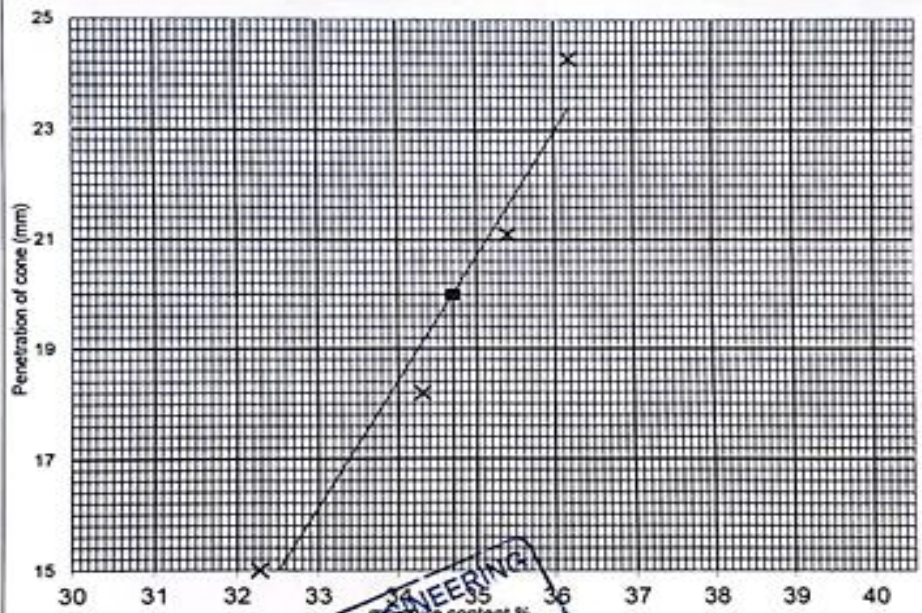
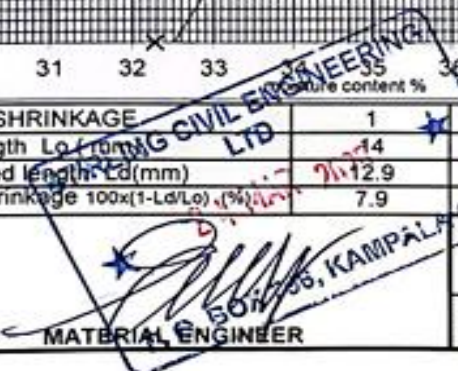
INSTITUTION		STUDENTS			LABORATORY		
 <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A Centre of Excellence in the Heart of Africa</small>		<b>MWESIGE JOTHAM</b> <b>KAKANDE HANNINGTON</b>					
PROJECT		ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS					
Location		Budondo sub-county Jinja District					
Test		Efflorescence test on unfired clay bricks					
Material description		Unfired clay bricks made from blending sodium silicate-activated granite dust and clay					
Molding date				4/Feb/2025			
Testing date				5/Mar/2025			
Age				28 days			
Clay % & GD %	Mix no.	Specimen no.	Exposed area of brick sides (mm <sup>2</sup> )	Area of efflorescence (mm <sup>2</sup> )	Efflorescence percentage (%)	Average efflorescence (%)	Efflorescence grade
100 and 0	Control	CS1	228.5X126.8	7.9X126.8	3.46	3.065	Slight
		CS2	228.4X126.9	6.1X126.9	2.67		
44 and 56	1	A1	228.4X127.1	41.5X127.1	18.17	20.245	Moderate
		A2	228.0X127.0	50.9X127.0	22.32		
45 and 55	2	B1	228.0X127.1	30.3X127.1	13.29	15.230	Moderate
		B2	228.3X126.9	39.2X126.9	17.17		
46 and 54	3	C1	228.5X126.9	32.8X126.9	14.35	12.320	Moderate
		C2	228.4X126.8	23.5X126.8	10.29		
47 and 53	4	D1	228.6X126.8	28.5X126.8	12.47	10.635	Slight
		D2	228.3X126.8	20.1X126.8	8.80		
48 and 52	5	E1	228.4X126.9	18.0X126.9	7.88	6.150	Slight
		E2	228.6X127.0	10.1X127.0	4.42		
49 and 51	6	F1	228.3X126.9	12.4X126.9	5.43	4.225	Slight
		F2	228.4X126.8	6.9X126.8	3.02		
50 and 50	7	G1	228.5X126.7	1.3X126.7	0.57	0.480	Slight
		G2	228.3X126.9	0.9X126.9	0.39		
51 and 49	8	H1	228.4X126.9	0.0X126.9	0.00	0.000	Nil
		H2	228.5X126.8	0.0X126.8	0.00		
52 and 48	9	I1	228.6X126.5	2.9X126.5	1.27	1.205	Slight
		I2	228.2X126.5	2.6X126.5	1.14		
53 and 47	10	J1	228.3X126.8	3.6X126.8	1.58	2.585	Slight
		J2	228.5X126.9	8.2X126.9	3.59		
				<u>Students</u>			
				_____ <b>Mwesige Jotham Kakande Hannington</b>			



INSTITUTION		STUDENTS		LABORATORY
 <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A Centre of Excellence in the Heart of Africa</small>		MWESIGE JOTHAM KAKANDE HANNINGTON		<b>Stirling</b>
PROJECT	ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS			
Location	Budondo sub-county Jinja District			
Test	Load bearing capacity for brick wall masonry (Axial load test BS 5628, 2005)			
Material description	Three course brick wall made from unburnt SS activated GD-clay bricks and general mortar.			
Constructing date	5/Mar/2025			
Testing date	17/Mar/2025			
Mortar strength ( $f_m$ )	3 MPa			
Brick dimension (mm)	228.6X127.2X76.4			
Brick compressive strength	4.92MPa			
Test Sample	A	B		
Wall panel width (mm)	730.8	728.1		
Bond thickness (mm)	15	15		
Wall panel height (mm)	245.4	246.2		
Wall panel thickness (mm)	127.4	127.4		
wall panel weight (g)	45943	45955		
Crashing force P (KN)	236.5	235.7		
Average crushing force	236.1			
 Material engineer		<u>Students</u> <hr/> Mwesige Jotham Kakande Hannington		



INSTITUTION		STUDENTS		LABORATORY
 <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A College of Excellence in the Heart of Africa</small>		<b>MWESIGE JOTHAM</b> <b>KAKANDE HANNINGTON</b>		<span style="border: 2px solid red; border-radius: 15px; padding: 5px; display: inline-block;">Stirling</span>
PROJECT	ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS			
Location	Budondo sub-county Jinja District			
Test	Load bearing capacity for brick wall masonry (Axial load test BS 5628, 2005)			
Material description	Three course brick wall made from unburnt clay bricks and general mortar.			
Constructing date	5/Mar/2025			
Testing date	17/Mar/2025			
Mortar strength ( $f_m$ )	3 MPa			
Brick dimension (mm)	228.6X127.2X76.4			
Brick compressive strength	1.98 MPa			
Test Sample	A	B		
Wall width (mm)	731.6	730.2		
Bond thickness (mm)	15	15		
Wall height (mm)	246.1	246.2		
Wall thickness (mm)	127.4	127.4		
Wall panel weight (g)	41950	41821		
Crashing force P (kN)	139.8	120.96		
Average crushing force	130.38			
Material engineer	 <small>P. O. BOX 738, KAMPALA (U)</small>		<u>Students</u> <hr/> Mwesige Jotham Kakande Hannington	

INSTITUTION		CLIENT		CONTRACTOR	
 <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A COLLEGE OF THE UNIVERSITY OF THE SOUTH PACIFIC</small>		<b>MWESIGE JOTHAM AND KAKANDE HANNINGTON</b>			
<b>STIRLING MUKONO LABORATORY</b>					
PROJECT		<b>ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS</b>			
<b>GRADING FOR CLAY BLENDED WITH GRANITE DUST</b>					
<b>(BS )</b>					
LOCATION:		Budondo subcounty		OPERATORS:	
SAMPLE No:		A		TOTAL DRY WT. OF SAMPLE: 5699.5	
MATERIAL DESCRIPTION:		CLAY MATERIAL BLENDED WITH GRANITE DUST		TOTAL DRY WT. OF SAMPLE AFTER: 5699.5	
				DATE SAMPLED: 14/12/2024	
				DATE TESTED: 2-Feb-25	
MAXIMUM SIEVE SIZE (mm)	WEIGHT RETAINED (gm)	PERCENTAGE RETAINED (%)	CUMULATIVE RETAINED	PERCENTAGE PASSING (%)	
63.0	0	0.0	0	100.0	
37.500	0	0.0	0	100.0	
20.000	0	0.0	0	100.0	
5.000	8.1	0.1	0.1	99.9	
2.000	715.6	12.6	12.7	87.3	
0.425	3966.9	69.6	82.3	17.7	
0.075	750.7	13.2	95.5	4.5	
PAN	258.2				
WEIGHT LOST DURING SIEVING	0				
TOTAL	5699.5				
5699.5					
Grading Curve					
					
			Students _____ MWESIGE JOTHAM KAKANDE HANNINGTON		

<b>INSTITUTION</b>  <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A Centre of Excellence in the Heart of Africa</small>		<b>CLIENT</b> <b>MWESIGE JOTHAM</b> <b>KAKANDE HANNINGTON</b>		<b>CONTRACTOR</b> <div style="border: 2px solid red; padding: 5px; display: inline-block;"> <b>Stirling</b> </div> Stirling Civil Engineering Ltd	
<b>PROJECT</b>		FINAL YEAR RESEARCH AND DESIGN PROJECT			
<b>GRADING FOR CLAY AND GRANITE DUST BLENDED MATERIAL</b> (BS 1377-2, 1990 )					
		<b>SAMPLE No.</b>		<b>DRY WT. BEFORE</b>	<b>DRY WT. AFTER</b>
<b>LOCATION:</b>		subcounty	B	5048.7	2902.6
<b>MATERIAL DESCRIPTION:</b>		CLAY MATERIAL BLENDED WITH GRANITE DUST		<b>DATE SAMPLED:</b>	14/12/2024
				<b>DATE TESTED:</b>	2-Feb-25
<b>MAXIMUM SIEVE SIZE (mm)</b>	<b>WEIGHT RETAINED</b>	<b>PERCENTAGE RETAINED</b>	<b>CUMULATIVE RETAINED</b>	<b>PERCENTAGE PASSING (%)</b>	
63.0	0	0.0	0	100.0	
37.500	0	0.0	0	100.0	
20.000	0	0.0	0	100.0	
5.000	8.1	0.3	0.2	99.8	
2.000	512.9	17.7	10.4	89.6	
0.425	1905.3	65.6	48.1	51.9	
0.075	441.1	15.2	56.8	43.2	
PAN	35.2				
<b>WIEGHT LOST DURING SIEVING</b>	0				
<b>TOTAL</b>	2902.6				
2902.6					
<b>Grading Curve</b> 					
 MATERIAL ENGINEER AMP... S. (U) P. O. BOX 755...			<b>Students</b> _____ <b>MWESIGE JOTHAM KAKANDE HANNINGTON</b>		

INSTITUTION		CLIENT		CONTRACTOR		
 UGANDA CHRISTIAN UNIVERSITY <small>A Centre of Excellence in the Heart of Africa</small>		MWESIGE JOTHAM AND KAKANDE HANNINGTON		<div style="border: 2px solid black; padding: 5px; display: inline-block;"> <b>Stirling</b> </div>		
PROJECT		<b>ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS</b>				
<b>ATTERBERG LIMITS BS 1377 PART 2:5:4-1990</b>						
Sample reference:				Sampling Date 16-Dec-24		
Location:		Budondo subcounty trial pit		Testing Date : 2-Feb-25		
Depth:		2				
sample description:		clay blended with activated granite dust				
<b>CONE PENETRATION METHOD</b>						
		Liquid limit (%)				Plastic Limit
LIQUID LIMIT Test No		1	2	3	4	(%)
Initial dial gauge reading mm		0	0	0	0	
Final dial Gauge reading mm		15	18.2	21.1	24.3	
Average penetration mm		16.6			22.7	
Container No.		BE	KO	BE	PI46	PIV6
Mass of wet soil +container g		50.60	50.10	53.00	52.05	58.21
Mass of dry soil +container g		39.97	39.56	41.22	40.59	44.66
Mass of container g		7.02	6.92	6.94	7.14	6.95
Mass of moisture g		10.6	10.5	11.8	11.5	13.6
Mass of dry soil g		33.0	32.6	34.3	33.5	37.7
Moisture content %		32.3	32.3	34.4	34.3	35.9
Average Moisture content %		32.3		34.3		35.4
						36.2
						24.1
						Liquid limit% <b>34.7</b> Plastic Limit % <b>24.1</b> Plasticity Index % <b>10.6</b> Reference:
<b>LINEAR SHRINKAGE</b> Initial length $L_0$ (mm)		1	2	Average Shrinkage		
Oven dried length $L_d$ (mm)		14	12.9			
Linear shrinkage $100 \times (1 - L_d/L_0)$ (%)		7.9	8.6	<b>8.2</b>		
				STUDENT		
<b>MATERIAL ENGINEER</b>				<b>MWESIGE JOTHAM KAKANDE HANNINGTON</b>		

INSTITUTION		STUDENTS	LABORATORY
 <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A Corner of Excellence in the Heart of Africa</small>		MWESIGE JOTHAM KAKANDE HANNINGTON	<b>Stirling</b>
PROJECT	ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS		
Location	Budondo sub-county Jinja District		
Test	Specific gravity test of clay material		
Material description	Fine clay material for brick making		
Sampling date	16/Dec/2024		
Testing date	20/Feb/2025		
Test Sample	A	B	
weight of Pycnometer (g)	509.78	537.63	
weight of (Pyk + water) g	1806.22	1768.52	
weight of (Pyc + water + sample) g	2127.46	2087.52	
SSD weight (g)			
Oven dry weight (g)	521.91	514.80	
SG (g/cm <sup>3</sup> )	2.601	2.625	
Avg SG (g/cm <sup>3</sup> )		2.610	
SG (kg/m <sup>3</sup> )		2610	
 Material engineer P. O. BOX 36, KAMPALA (U)		<u>Students</u>	
		Mwesige Jotham Kakande Hannington	

INSTITUTION		STUDENTS		LABORATORY
 <b>UGANDA CHRISTIAN UNIVERSITY</b> <small>A Centre of Excellence in the Heart of Africa</small>		<b>MWESIGE JOTHAM</b> <b>KAKANDE HANNINGTON</b>		<b>Stirling</b>
PROJECT		ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS		
Location		Budondo sub-county Jinja District		
Test		Specific gravity test of granite dust material		
Material description		Gray granite crusher dust material for blending with clay in brick making		
Sampling date		16/Dec/2024		
Testing date		20/Feb/2025		
Test Sample		A	B	
weight of Pycnometer (g)		509.78	537.63	
weight of (Pyk + water) g		1806.22	1768.52	
weight of (Pyc + water + sample) g		2096.44	2059.09	
SSD weight (g)		467.08	468.86	
Oven dry weight (g)		458.51	460.69	
SG (g/cm <sup>3</sup> )		2.725	2.716	
Avg SG (g/cm <sup>3</sup> )		2.720		
SG (kg/m <sup>3</sup> )		2720		
Water absorption (%)		1.87	1.77	
Avg water absorption (%)		1.82		
		<u>Students</u>		
		_____ <b>Mwesige Jotham    Kakande Hannington</b>		

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 quote No.....



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 DIRECTORATE OF GOVERNMENT  
 ANALYTICAL LABORATORY  
 Plot No. 2 Lourdel Road  
 Wandegaya,  
 P.O. Box 105639  
 Kampala - Uganda

DFD 052/2025

14<sup>th</sup> March 2025

MR. MWESIGYE JOTHAM AND MR. KAKANDE HANNINGTON  
 REG NO. S20B32/009 & S21B32/069  
 UGANDA CHRISTIAN UNIVERSITY  
 P.O BOX 4,  
 MUKONO-UGANDA  
 Tel: 256-780-314873

**REPORT OF ANALYSIS**

**Description of the Samples**

One sample in a transparent polythene bag containing grey material sample was submitted by Mr. Kakande Hannington, on 04<sup>th</sup> March 2025, and analysed on 12<sup>th</sup> March 2025. A summary of the sample received is shown in table below

S/N	Description	Quantity	Assigned Lab ID
1	Grey powdered material substances from granite dust and clay soil packed in a transparent polythene bag.	01	Sample "A" DFD 052/2025

**Analysis Requested**

Elemental analysis

**Method of Analysis**

Elemental analysis was done using the XRF Method.

**Results of Analysis**

The above sample has been analyzed with the following results as below.

Parameter	Units	Results for DFD 052/2025 Grey powdered material sample
Silicon dioxide	% m/m	59.07
Aluminium oxide	% m/m	29.61
Iron (III) Oxide	% m/m	4.90
Calcium oxide	% m/m	2.30
Titanium dioxide	% m/m	1.40
Phosphorous pent oxide	% m/m	1.01
Potassium Oxide	% m/m	0.82
Magnesium (II) Oxide	% m/m	0.63
Sodium Oxide	% m/m	0.26

**Remarks**

1. Results relate to sample analyzed and are reported as on received basis.

*Signed* 14/03/25  
 Semalago Fredrick  
 Government Analyst

APPENDIX C: DESIGN DRAWINGS OF THE FINAL BRICK PRODUCT

