ASSESSING THE SUITABILITY OF SODIUM SILICATE ACTIVATED GRANITE DUST IN THE MANUFACTURE OF UNFIRED CLAY BRICKS

JOTHAM MWESIGE

S20B32/009

A FINAL YEAR RESEARCH AND DESIGN PROJECT REPORT SUBMITTED TO THE FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A DEGREE OF BACHELOR OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING OF UGANDA CHRISTIAN UNIVERSITY

April, 2025

UGANDA CHRISTIAN UNIVERSITY

A Centre of Excellence in the Heart of Africa

ABSTRACT

This document contains a comprehensive account of the research conducted in the field of structural engineering in the section of masonry. Research was conducted to assess the suitability of sodium silicate-activated granite dust in the manufacture of unfired clay bricks in the quest for solutions to failure for brick making in Budondo sub-county, Jinja district, Eastern Uganda. The study was conducted to provide a masonry unit in to proximity of the local population who incur higher expenses over buying bricks from a distant area. Unfired bricks have gained favor by the Sustainable Development Goals, conventions, and protocols, where there is a need to reduce the carbon footprint and environmental protection. Sodium silicate-activated granite dust is a geopolymer that both chemically and physically modifies clay soils to become suitable for brick making. Clay soils used have a grading modulus of 0.05, PI of 16.8%, Sg of 2.61, and lower chemical suitability for brick making of 25.85%. Granite dust used had a grading modulus of 1.368, Sg of 2.72, and chemical suitability of 94.78%. Sodium, silicate activator had a modulus of 1.29 with 56.4% silica, and 43.6% sodium, making it suitable for activating granite dust (Provis & Van Deventer, 2009) On blending local clay with activated granite dust the improvement of grading modulus of 1.905, chemical suitability was 96.11% PI was 10.6%. It was found that unfired bricks made from sodium silicate activated granite dust had a compressive strength of 4.9MPa and load bearing capacity of 138.96KN accrued to good bearing capacity for low-cost buildings and self-weight walls. The brick had a water absorption capacity of 13.75% and efflorescence value which showed nil results. The brick is therefore good for masonry wall construction. The content in this document is organized in five chapters with chapter one having the introduction part of the study, chapter two contains the literature review and chapter three contains the methodology which explains how to obtain the objectives of the study. Chapter four is detailed with results and

discussions of the study, and the final chapter, which is chapter five, contains the conclusions and recommendations.

DECLARATION

I Jotham Mwesige, with registration number S20B32/009, affirm that the content of this report is my work, which is due to my research at the level of literature review. Any assistance provided, if noticed, has been for guidance. This piece of work is to be submitted to the Department of Engineering and Environment as a partial fulfillment for the award of the bachelor's degree in civil and environmental engineering

Mwesige Jotham

Sign: ______________

Date: __/_____/2025

APROVAL

I ratify that the piece of final year research and design project work as reported in this document was done by the respective students under my supervision at all stages of the research.

Supervisor

________________________   Date: __/____/2025

Mr. MWANJE TOM MORE

DEDICATION

This document is dedicated to my family, who have rendered endless support to me throughout my life. Not forgetting Mrs. Parker Catherine for the love, care, and generosity, only God can repay with the best suit. This document is furthermore dedicated to Ms. Judith Kataike Higenyi, who constantly upholds me and encourages me to be the best.

ACKNOWLEDGEMENT

Glory to the almighty god for all mighty works overwrought by his mighty hand. Heartfelt Praises to God the Father, the Son, and the Holy Spirit.

My applause to my family and friends for their sacrifices rendered to me so that I can reach the apex of this academic journey. All efforts are not in vain.

Heartfelt gratitude to the esteemed Engage Hope, Hopeshine Uganda, Teenage Mothers Outreach, Jesus is King Ministries International, and E3 partners for their effective ministration in my life and the opportunities given to me.

My applause to my friend and project partner, Mr. Kakande Hannington. All effort toward the success of the project is highly appreciated. Working with you on this project is a lifelong experience.

Gratitude to my project supervisor and Head of Department of Engineering and Environment, Mr. Mwanje Tom More. All your insightful guidelines and efforts towards the success of this project are highly appreciated.

My applause to the Research coordinator, Mr. Tayebwa. Thanks for the arrangements and programs made so that productive research could be conducted.

Heartfelt gratitude to the class of Bachelor of Science in Civil and Environmental Engineering 2025. This class means a family.

CONTENTS

ABSTRACT i

DECLARATION iii

DEDICATION v

ACKNOWLEDGEMENT vi

CHAPTER ONE: INTRODUCTION 1

1.1. Background 1

1.2. Problem statement 2

1.3. Objectives of the study 3

1.4. Research questions 4

1.5. Justification 4

1.6. Significance of the study 5

1.7. Scope of the study 5

1.7.1. Contextual scope 5

1.7.2. Geographical scope 5

1.7.3. Time Scope 6

CHAPTER TWO: LITERATURE REVIEW 6

2.1. Introduction 6

2.2. Clay soils 7

2.2.1. Clay soils in Budondo 8

2.2.2. Clay Soils for Brick Making 8

2.2.3. Physical Properties of Clay Soils for Brick Making 9

2.2.4. Chemical Properties of Clay Soils for Brick Making 9

2.2.5. Modified Clay Soils and Unfired Clay Bricks 10

2.3.5.1. Mechanical and Chemical Modification 10

2.2.6. Unfired Clay Bricks..10

2.2.7. Fired clay brickmaking 10

2.3. Sodium silicate activated granite dust..11

2.3.1. Sodium Silicate...11

2.3.2. Suitability of the geopolymer 12

2.4. Comparison with other Brick innovations...12

2.4.1. Compressed earth Bricks (CEB) 12

2.4.2. Interlocking Stabilized Soil Bricks (ISSB) 12

2.4.3. Fired clay bricks...13

2.5. Conclusion 14

CHAPTER THREE: METHODOLOGY 15

3.1. INTRODUCTION 15

3.2. MATERIALS AND METHODS...15

METHODS 17

3.2.1. To determine the physical and chemical properties of local clay soils for brick making 17

3.2.3. Effect of sodium granite dust on the physical, chemical properties and load bearing capacity of unfired clay bricks and determining the best proportion of the dust for the mix to form a composite 21

CHAPTER FOUR: RESULTS AND DISCUSSION 26

4.1. INTRODUCTION 26

4.1.1 CLAY SOIL SAMPLE FROM BUDONDO SUB-COUNTY IN JINJA DISTRICT 26

4.1.1.1. Particle size distribution for clay soils..26

4.1.1.2. Atterbag limits test for Budondo clay soils...................................28

4.1.1.4. Chemical composition of clay soil 31

4.2. GRANITE DUST SAMPLE FROM MM STONE QUARRY IN BUDONDO SUB-COUNTY IN JINJA DISTRICT 33

4.2.1. Specific gravity of granite dust 33

4.2.2. Grading of granite dust 34

4.2.3. Chemical composition of granite dust 36

4.2.4. Chemical composition of prepared sodium suilicate 37

4.2.5. Compressive strength test of activated granite dust 38

4.2.6. Water absorption of activated granite dust 42

4.3.1. Particle size distribution of the SS activated GD and clay blended material (BS 1377 part 2 1990)...45

4.3.2. Atterbag limits test for the SS activated GD and clay blended material (BS 1377 part 2 1990) 47

4.3.3. Chemical composition test for the blended material 48

4.3.4. Efflorescence test for the final SS activated GD unfired clay brick 49

4.3.6. Water absorption test of the SS activated GD clay bricks 55

4.3.7. Load bearing capacity of the short three wall course.........................57

4.4. Brick drawing 59

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS 60

REFERENCES 62

APPENDIX A: TABLES OF RESULTS AND QUANTIFICATION 67

APPENDIX B: PHOTOS DURING LABORATORY WORK 71

APPENDIX C: LABORATORY RESULTS 72

LIST OF TABLES

Table 4. 1: Grading criterion of clay soils 27

Table 4. 2: Specific gravity standard ranges 31

Table 4. 4: Chemical suitability of local clay soils from Budondo 33

Table 4. 5: Recommended specification on granite fines (Sourced from Neolith technical manual) 35

Table 4. 6: Key mineral compounds in the granite dust from MM stone quarry in Budondo sub-county 36

Table 4. 7: Suitability of granite dust.. 37

Table 4. 8: Chemical composition of the sodium silicate prepared from the silica fumes 37

Table 4. 9: Modulus of sodium silicate... 38

Table 4. 10: Compressive strength of sodium silicate activated granite dust at 7 days 38

Table 4. 11: compressive strength of sodium silicate activated granite dust mortar at 28 days.. 40

Table 4. 12: Water absorption results analysis 42

Table 4. 13: Chemical suitability of the blended material 48

Table 4. 14: Efflorescence results for the final bricks materials 50

Table 4. 15: Compressive strength of unfired clay bricks made 52

Table 4. 16: Decrement in water absorption of SS activated GD bricks 56

Table 4. 17: Load bearing capacity of brick wall panel 58

Table 1: Masses of individual constituents required to make a single brick 67

Table 3: porosity ranges..68

Table 4: Summary of lab results and the standard value 69

Table 5: Classes of bricks 70

Table 6: Summary of laboratory results for the brick...70

LIST OF FIGURES

Figure 1.1: geo-polymerization reaction of granite dust 5

Figure 4. 1: Grading of clay sample from Budondo subcounty 26

Figure 4. 2: Clay atterbag graphs 28

Figure 4. 3: Atterbag limits results on a plasticity chart (Sourced from BS 5930:2015) .. 30

Figure 4. 4: Grading of granite dust 35

Figure 4. 5: Compressive strength of activated granite dust at 7 days 39

Figure 4. 6: Compressive strength of activated granite dust at 28 days 41

Figure 4. 7: Quadratic regression analysis of compressive strength of GD 41

Figure 4. 8: Water absorption of activated granite dust 43

Figure 4. 9: Water absorption analysis using quadratic regression analysis tool 44

Figure 4. 10: Grading curve for blended material 45

Figure 4. 11: Atterbag limits for blended material 47

Figure 4. 12: Compressive strength of bricks at 7, 14 and 28 days of maturity 52

Figure 4. 13: Average compressive strength of SS activated GD bricks 53

Figure 4. 14: Water absorption of the final brick at 7, 14 1nd 28 days of maturity 57

Figure 4. 15: Brick elevations 59

Figure 1: Sampling of granite dust 71

Figure 2: Sampling of clay soils from Budondo 71

Figure 3: Grading of samples by sieve analysis 71

Figure 4: Mixing of granite dust with sodium silicate..*71*

Figure 5: Casting of activated granite dust cubes...*71*

Figure 6: Crashing of the partially hardened clay sample....................................*71*

Figure 7: Mixing activated GD with clay for brick making....................................*71*

LIST OF ACRONYMS

AASHTO:	American Association of State Highway and Transportation Officials
ASTM:	American System of Testing and Materials
BS:	British standard
CEB:	Compressed Earth Bricks
ISSB:	Interlocking Stabilized Soil Bricks
GD:	Granite Dust
LL:	Liquid Limit
LS:	Linear Shrinkage
MoWT:	Ministry of Works and Transport
PI:	Plasticity Index
PL:	Plastic Limit
SG:	Specific Gravity
SH:	Sodium Hydroxide
SS:	Sodium Silicate
XRF:	X-Ray Refractometer

CHAPTER ONE: INTRODUCTION

1.1. Background

Unfired clay bricks are clay masonry units made from the molding of clay into desirable shapes, cured under low temperature or air dried and not burnt in a kiln (Harriet et al, 2021). According to British standard for clay bricks: BS 3921-1985, the unfired clay brick has a dimension of 225*112.5*75 and a working dimension of 215*102.5*65mm. Unfired clay bricks are environmentally friendly in terms of production since energy is not involved in the manufacture of unfired clay bricks (Sutton et al, 2011). Unfired clay bricks are used for the construction of both load-bearing and non-load bearing walls, although are effective when used in the interior walls since unfired clay bricks are highly affected by weather conditions like rain which causes erosion of the unfired brick and low characteristic compressive strength (Sutton et al, 2011).

Different innovations like the Compressed Earth bricks (CEB), Interlocking Stabilized soil bricks (ISSB)have been developed and produced positive results to improve the mechanical properties (compressive strength, water absorption, freezing and thawing, density, tensile and flexural strength) of unfired clay bricks (Raj et al, 2023). These innovations involve use of expensive materials like cement during the manufacture of unfired clay bricks which makes the production of the unfired bricks less economical (Raj et al, 2023).

Fired clay bricks are predominantly used for the construction of structural walls, but their production is associated with the use of higher energy levels of energy (800^{o}c to 2000^{o}c) from burning of either renewable or nonrenewable fossil fuels (Muheise and Pavia, 2021).

Burning of clay bricks results into the burning of organic substances, Sulphur and carbonates present in clay material leading the emission of carbon dioxide, carbon monoxide, Sulphur dioxide and nitrogen oxides which results in the increase of greenhouse effect gases hence contributing to global warming (Muheise & Pavia, 2021).

Nevertheless, there has been use of different materials like saw dust, rice husk ash among other stabilizers to improve the chemical and mechanical properties of clay soils used to manufacture bricks of good compressive, tensile, flexural strength and water absorption as well as good resistance to freezing and thawing and low efflorescence (Turgut &Algin, 2021).

This research is therefore aimed at assessing the suitability of using sodium silicate activated granite dust to improving the physical, mechanical and chemical properties of unfired clay bricks as an environmentally friendly and cost-effective masonry unit.

1.2. Problem statement

There is no brick making in the area of Budondo Sub County due to presence of poor local soil characteristics that make the molded brick to crack, disintegrate and also break during the process of sintering (Harriet et al, 2021). Local soils in Budondo contains 96.3% silty-clayey and 3.6% sand which leads to brick failure during curing due to shrinkage cracking (Harriet et al, 2021). Due to the failure of the bricks in the area of Budondo sub-county, approximately 36.3% of the dwellings resorted to either construction of temporary wall building materials or incurring high transportation costs involved in sourcing bricks from the neighboring areas like Walukuba village Modifying the local clay soils with sand and gravel in a ratio of 1:2 to produce burnt clay bricks resulted in a brick with a low compressive strength of 1.9N/mm2, which is below the minimum limit of 5N/mm2 recommended in BS 3921-1985 and also had a higher water absorption of 20.5% which was above the recommended maximum limit of 18% according to EN 1996-2:2006.

This implies the brick in Budondo subcounty failed to meet the durability standards (Arasa et al, 2021). In addition, fired clay bricks production emits greenhouse gases like carbon dioxide during the kiln process of sintering, resulting to global warming and climatic changes (Singh et al, 2024).

There is therefore need of more sustainable bricks with improved mechanical properties in the area of Budondo sub-county. One of the materials that have been highly used to modify clay soils for unfired bricks is granite dust however, narrow research has been conducted to the using of granite dust as a geopolymer. In addition, low compressive strength geopolymer resulted from the use of secondary stabilizers in the brick due to the low silica content ready to dissolve in the alkaline solution (Josh 2023). It is to this note that the use of sodium silicate activated granite dust is proposed to be used as clay soil modifier to manufacture unfired clay bricks with improved mechanical properties

1.3. Objectives of the study

Main objective

To assess the suitability of sodium silicate activated granite dust in the manufacture of unfired clay bricks

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.

1.4. Research questions

1.5. Justification

Clay soils are characterized with poor gradation which makes them poor soils for the manufacture of bricks (Tang et al., 2022). In order to improve mechanical properties of the clay soils, granite dust is mixed with the clay to form a well graded soil material with a rigid frame work with in the clay matrix to enhance their mechanical properties, granite dust addition can turn the mix into a well graded complex that yields a high confinement to make it suitable for brick making (Amulya, Moghal and Almajed, 2021).

Adding granite dust to the clayey soil can fill the voids in the cohesive soils which increases its density and compressive strength through the formation of a rigid framework within the soil. Mixing granite dust with clay lowers the plasticity of the clay soils, however this reduces the cohesion, which is the binding power of the clay particles (Amulya, Moghal and Almajed, 2021). This results into the failure of the mix and hence need to introduce a binder that can hold granite dust particles together with clay particles to form a composite.

By activating granite dust using sodium silicate leads to formation of a cementitious gel that binds the clay particles together through a pozzolanic reaction that leads to the formation of hydro-aluminate-oxy-silicate complex that improves the cohesion, compressive strength, density and water absorption of the mix

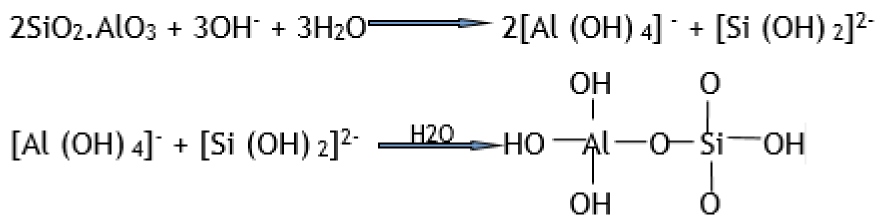


Figure 1.1: geo-polymerization reaction of granite dust

1.6. Significance of the study

This research is aimed at determining a cheaper and environmentally friendly technique of manufacturing unfired clay bricks, thereby improving the quality of the unfired clay breaks on the market and making them available to the local population in the area of Budondo sub county where higher expenses are incurred in the purchase and transportation of fired bricks from the neighboring communities like Mbiko (Oti, 2010)

1.7. Scope of the study

This section highlights the coverage of the research and design project

1.7.1. Contextual scope

This study is specifically in the structural engineering in the section of brick masonry. The study is focused on production of environmentally friendly unburnt clay bricks that are to be used as masonry units for the construction of residential structures for the people (Curtin et al., 2006). This will involve the improvement of the load bearing of unburnt clay bricks and the durability of the clay bricks so that they are used for the construction of the brick at all weather conditions. This is to be achieved through improving the mechanical properties of unfired clay brick and make them available to the local population.

1.7.2. Geographical scope

The study was conducted in Buleeba village in Budondo sub-county in Jinja East Jinja District in the Eastern part of Uganda (Harriet et al., 2021). At grid reference; 0.534650E:33.163012

1.7.3. Time Scope

The study is designed to be carried out for a period of 8 months starting from the month of September 2024 to April 2025

CHAPTER TWO: LITERATURE REVIEW

2.1. Introduction

Bricks are masonry units used for both load bearing and non-load bearing wall construction to raise a structure (Suton et al., 2011). Brick production in the brick making industry makes one of the oldest produces in the constructions industry with production of both fired clay bricks and unfired clay bricks of different shapes and purposes (Suton et al., 2011) Bricks are used for purposes like wall construction, surface pavement, fireplace construction facing design depending on the nature of the brick. There are different types of bricks on market as solicited here, engineering bricks, facing bricks, paving bricks, hollow and solid brick all serving in the respective parts in the construction of walls and other structures (Beamish & Donovan, 1993). Bricks are however made from molding of clay into the desired shape, cured and sintered in the kiln to produce a bright colored fired clay brick that has good mechanical properties that enhance the load bearing capacity of the masonry units (Fattah, Fathi and Kamal, 2019) However the production of fired bricks is involved with use of high energy levels from $800^{o}c$ to $2000^{o}c$ which is obtained from the burning of fossil fuels resulting into the emission of greenhouse gases like carbon dioxide, whose increased concentration exacerbates global warming and hence climatic changes. The use of environmentally friendly construction means like compressed earth bricks and the Interlocking Stabilized Soil Bricks is embarked by the construction industry and it is on this note that sodium silicate activated granite dust is a potential additive in the clay material to enhance the mechanical properties of unfired clay bricks (Oti, 2010).

2.2. Clay soils

Clay soils are the primary requisite for the making of bricks. According to the grading guidelines provided in BS 1377 part 2 1990, clay soils are fine grained materials with particle size of less than 0.002mm; this implies clay particles pass sieve number 200 (0.075mm) the separation sieve for fine grained material (that is: silt and clay) (BS 1377, 1990).

Clay mineralogy is mainly silica and alumina in chemical composition, and it exists as kaolinite, Illite and, or montmorillonite clay. Kaolinite clay is a product of chemical weathering of feldspar rocks, has a white powdered appearance, fine grained and considered the purest form of clay with lower water absorption, and chemical formulae $Al_2O_32SiO_2.2H_2O$ (Nepal, 2008).

Illite is one of the most common and readily abundant form clay minerals in soils around the world. Illite clay has higher quantities of potassium oxide which gives them a melting point of about 1050 -1150oc thus firing of the Illite clay brick is recommended to be within this range (Nepal, 2008).

Montmorillonite clay mineral has a good property of exchange cations: Al ion is exchanged with other cations like magnesium ion in the clay mineral. This gives the clay mineral a higher plasticity, higher water absorption and greater linear shrinkage making it not desirable for break making because it easily breaks on sintering due to rapid loss of water content (Nepal, 2008). This clay mineralogy has can be off white, pale pink, beige to gray in color and has a melting point ranging from 1200^{o}c to 1750^{o}c (Craig, 2004).

2.2.1. Clay soils in Budondo

Bricks are made from molding clay soils into the desired shape. The local clay soils in Budondo subcounty have a poor gradation of 96.3%clayey silt and 3.7% sand soils which makes break making unfeasible through shrinkage cracking and failure during the curing process (Harriet et al., 2021). According to Fattah, Fathi and Kamal (2019), Clay soils good for brick manufacturing should have a grade modulus between 2.0 to 3.5 and the lower the grade modulus the finer the clay and the best for brick making and Kumar, Bhardwaj and Mathura (2017) indicate that Grade A clays are the best for brick making due to their fineness, high plasticity and high cohesion. With local clay soils that have more courser particles, a binder has to be introduced to enhance the grade and improve the mechanical properties of the clay making it good for brick manufacturing. Geopolymers are good stabilizers as they introduce pozzolanic properties in the clay matrix through the pozzolanic reaction between the clay particles and the active pozzolanic elements in the pozzolans (Davidovits, 2015)

2.2.2. Clay Soils for Brick Making

Clay soils are a cornerstone of brick production due to their favorable physical properties, including plasticity, cohesiveness, and workability. Derived from feldspathic rock weathering, these soils contain mineral components such as kaolinite and montmorillonite, which influence their behavior. Kaolinite provides thermal stability and minimal shrinkage, making it desirable for molding processes, whereas montmorillonite, despite its high plasticity, poses risks of excessive shrinkage and cracking (Vieira et al).

2.2.3. Physical Properties of Clay Soils for Brick Making

2.2.3.1. Particle Size Distribution

The particle size distribution of clay soils is critical for determining their suitability in brick manufacturing. Ideally, a mix containing 20-30% clay, 30-50% silt, and 20-30% sand enhances cohesiveness and minimizes cracking during drying.

A well-graded particle distribution improves strength and dimensional stability, which is vital for producing bricks that meet structural and aesthetic requirements (Polakowski et al., 2021).

2.2.3.2. Atterberg Limits

Atterberg limits, including the liquid limit, plastic limit, and plasticity index, provide insight into the molding and drying characteristics of clay. Clays with a plasticity index of 15-35 are considered ideal for brick production as they balance workability with resistance to cracking during drying (Andrade et al., 2011).

2.2.3.3. Specific gravity (SG) test for local clay soils (AASHTO T100)

The Specific gravity of the soil is the measure of the material's density relative to the density of water. It is one of the properties of the material that can inform the material's water absorption, compaction and how the particles of the material can be packed for higher density. Materials with lower specific gravity have higher water absorption, lower compaction and lower densities, compared to materials with higher specific gravity (Mitchell and Soga, 2005).

2.2.4. Chemical Properties of Clay Soils for Brick Making

2.2.4.1 Chemical Composition

Clay soils are rich in silica and alumina, which confer plasticity, strength, and thermal stability. Secondary oxides such as oxides of calcium and magnesium, iron, potassium and sodium also play a role in enhancing durability colour of the brick and workability of the clay mix. An optimal SiO2:Al2O3 ratio of 2:1 is essential for achieving robust and durable bricks (Chindaprasirt et al., 2012).

2.2.5. Modified Clay Soils and Unfired Clay Bricks

2.3.5.1. Mechanical and Chemical Modification

Clay soils are often modified to improve their engineering properties for brick production. Mechanical methods, such as blending and compacting, optimize particle size distribution and improve load-bearing capacity.

Chemical modification using binders like sodium silicate enhances the compressive strength and water resistance of bricks through the formation of cementitious gels (Amulya et al., 2021).

2.2.6. Unfired Clay Bricks

Unfired clay bricks, also known as sun-dried bricks, are gaining popularity as a sustainable alternative to traditional fired bricks. These bricks rely on mechanical and chemical stabilization rather than kiln firing, significantly reducing energy consumption and carbon emissions. The integration of activated granite dust in unfired clay bricks improves their compressive strength, water resistance, and load-bearing capacity, aligning with sustainability goals in the construction industry (Lachheb et al., 2023).

2.2.7. Fired clay brickmaking

Fired clay bricks are made from the sintering of fully hardened clay bricks to high temperature (800–1200ºc) to form a very hard brick material with low water absorption, high compressive strength and sufficient load bearing capacity for the intended use. Fired clay have a bright reddish or yellowish color and produce a sharp sound (Amulya et al., 2021). Chindaprasirt et al., (2012) quotes that fired bricks are tough on abrasion and have long term sustainability. However, Andrade et al., (2011) discusses the environmental concerns of fried bricks as sintering activities contributes to the carbon dioxide emission and deforestation which are detrimental activities to the environment.

2.3. Sodium silicate activated granite dust

2.3.1. Sodium Silicate

Sodium silicate, commonly known as water glass, is a key additive in enhancing the binding properties of brick-making materials. Its chemical reactivity in alkaline environments leads to the formation of durable matrices, improving the strength and cohesion of bricks (Phoo-ngernkham et al., 2015).

Sodium silicate activated granite dust is a geopolymer introduced to form a rigid framework within the clay matrix through binding particles of the clay together with those of the granite dust. Geopolymers are formed by reacting the alumina and silica materials with alkaline activators. The process starts with dissolving silica fumes in the 1M sodium hydroxide to form a high silica content alkaline compound of sodium silicate. The sodium silicate is then used to activate the granite dust to form the granite dust geopolymer (Turgut&Algin, 2021). Sodium silicate is an activator that is used in this process to achieve a good granite dust geopolymer with high content of silica and alumina. Davidovits, (2015) shows that geopolymers possess high compressive strength, low water absorption and good durability which makes them excellent for use in the manufacture of masonry units like unfired clay bricks. Sodium silicate activated granite dust can be used to majorly stabilize silty clayey soil which often suffer from low compressive strength and high-water absorption, thereby enhancing the mechanical strength of the bricks including their density and porosity Ghosh (2019).

The fact that the local soils in Budondo have more silt clayey content (96.3%) and sand content of 3.7%, and lower grading modulus of 0.08. Bricks made from soils with such a grading modulus are weak with low compressive strength 1.9N/mm^2 which is below the minimum standard of 5N/mm^2, lower density, higher water absorption of 20.5% which is way higher the minimum water absorption rate of 18% and impaired durability.

The integration of the sodium silicate activated granite dust in the local clay soils will help to enhance the mechanical properties like the compressive strength, lowering the water absorption (BS EN 771-1: 2011)

2.3.2. Suitability of the geopolymer

According to Zhang et al. (2020) adding a geopolymer in the clay soil enhances the performance of the unfired clay bricks through increasing the compressive strength, density of the brick and relatively reducing the water absorption. On the same note, geopolymers are excellent binders that improves the physical properties of the clay soil with poor gradation and enhances the curing of the mix at an ambient temperature (Palamo et al., 2014).

In Budondo sub-county, the inclusion of sodium silicate activated granite dust will improve the gradation of the local clay soils resulting in the manufacture of bricks with improved mechanical properties of compressive strength, density water absorption since sodium silicate activated granite dust geopolymer is durable with high compressive strength even when weather conditions are not favorable (Kumar et al., 2017).

2.4. Comparison with other Brick innovations

2.4.1. Compressed earth Bricks (CEB)

Compressed Earth Bricks is another alternative to the fired clay bricks made by compacting a mixture of soil and a specific amount of the cement or lime. According to Walker and Stace (2017), Compressed Earth Bricks offer improved compressive strength however the water absorption is still an issue irrespective of the high costs involved.

2.4.2. Interlocking Stabilized Soil Bricks (ISSB)

This innovation is employed to improve the mechanical strength of unfired clay bricks in which cement and, or lime are used as stabilizer to form a rigid framework within the clay matrix.

They are designed to use less mortar as they interlock with one another when used to build masonry walls. Like the compressed Earth bricks, the interlocking Stabilized Soil bricks offer good compressive strength and durability relative to the fired clay bricks and are environmentally friendly, although they are associated with high costs of production (Maina et al., 2016)

According to research conducted by Xie et al. (2018) shows that sodium silicate stabilized polymers provide higher mechanical properties compared to other stabilizers as they give a higher compressive strength and lower water absorption which informs the durability of the composite formed, while using locally available materials like granite dust a waste material from granite quarry and silica fumes a nuisance from steel rolling companies. Hence use of sodium silicate activated granite dust improves the mechanical properties of unfired clay bricks at a lower cost compared to CEB and ISSB. It is therefore workable even at the low-income states. According to Razak et al. (2018), using local materials in construction significantly reduces costs while promoting sustainable development.

2.4.3. Fired clay bricks

Fired clay bricks are the predominant bricks used in the masonry as offer excellent mechanical properties of compressive strength, low water absorption rate and durability. However, the production of fired clay bricks is associated with the emission carbon dioxide which is a greenhouse gas that exacerbates global warming.

The use of sodium silicate activated granite dust is an alternative to overcome the issue of environment degradation caused by the emission of greenhouse gases.

Additionally, granite dust used as a geopolymer is waste material from granite quarrying which reduces the need to have a virgin material to be used in the stabilization of the clay soil for the manufacture of unfired clay bricks (Zhang et al., 2020)

2.5. Conclusion

Sodium silicate-activated granite dust gives great hope as an additive for improving the mechanical properties and durability of unfired clay bricks, particularly in areas with poor soil gradation like Budondo sub-county. The high silica and alumina content of granite dust, combined with the binding properties of sodium silicate, can address the limitations of traditional brick-making methods, offering an environmentally friendly, cost-effective solution.

In addition, this solution is not only addressing the compressive strength and water absorption challenges faced in unfired clay bricks but also aligns with the sustainable development goals as it involves reduction of carbon dioxide emission.

CHAPTER THREE: METHODOLOGY

3.1. INTRODUCTION

This chapter discusses how to achieve the objectives of this research. Since this is applied research, the objectives are to be achieved basing on tests as provided by national standards like the British Standard and Eurocode and ASTM among others. Tests discussed in the methodology are those one which can be done in the laboratories within the country of Uganda to avoid high costs and variation of properties when disturbed.

3.2. MATERIALS AND METHODS

MATERIALS

Materials which were used in the process of sodium silicate activated granite dust clay bricks in this section.

a). Granite dust

The granite dust was sourced from MM Stone Quarry in Buleeba village in Budondo sub-county. Enough granite dust is to be sourced from MM quarry which is producing 25000 tons of granite dust per year. 1000kg of granite dust be obtained and sealed in airtight sacks for storage, preconditioned to make the granite dust ready for geo-polymerization (Kumar et al., 2017)

b). Sodium hydroxide solution

Sodium hydroxide is a strong base with a pH level of 12. 10 molar concentrated sodium hydroxide solution was sourced from Jinja Marine Supplies in Nyenga zone. This was used to dissolve silica fumes obtained from MMI steel roling company to form sodium silicate that will activate granite dust. 500G of Sodium hydroxide pellets were completely dissolved in 500ml of distilled water and the solution let to stand cooling.

After the solution was cool, it was diluted so that the solution forms 1000ml to form 10M sodium hydroxide (Xie et al., 2018).

c). Sodium silicate

The sodium silicate was obtained from silica fume that was sourced from MMI steel industry in Walukuba, Jinja district. About 100kg was obtained and preconditioned following the procedure below.

Preparation of sodium silicate

The silica fume was washed with distilled water to remove dissolved impurities and air dried for a week. Dried sample of washed silica fumes was passed through the magnetic separator to remove any metallic impurities. The silica fume was added to concentrated sodium hydroxide solution and stirred to create a homogeneous mixture which was left to stand for about 6 to 12 hours. The silica fume solution was sieved by passing it through a 500-mesh poly-propylene fabric sieve of opening diameter 25 micron allowing for collection of liquid sodium silicate in a container placed at the bottom of the sieve (Turgut &Algin, 2021)

d). Clay soil

Local clay soils were sourced from Buleeba village in Budondo subcounty where the soils are attributed to be of poor gradation and cannot be used to manufacture bricks according to Harriet et al., 2021. The were extracted using trial pits at a depth of 2m and a span of 6m from each trial pit. Three trial pits were excavated and the samples mixed together for integration and homogeneity of the sample obtained (BS 5930, 1990).

METHODS

3.2.1. To determine the physical and chemical properties of local clay soils for brick making

a) Specific gravity test

The test was conducted according to AASHTO T100 to determine the water density of the clay material. The major aim of the test was to determine the voids of the material and have an understanding of the packing of the particles in the clay material. The test was conducting through oven drying the clay soil sample for about 24 hr. The oven dried sample was weighed on the scale with a precision of three decimal places put in calibrated pycnometers, submerged the sample with water and left to stand for about 1hr. The pycnometers were filled with water, shaken to expel all air bubbles and weighed to obtain the mass of (pycnometer+ sample+ water) (AASHTO,2020)

b) Particle size distribution test

The test was carried out in accordance to BS 1377: Part 2: 1990 using the method of sieve analysis. This test was conducted to determine how much of each particle size was present in the local clay soils which were later improved and used for brick making. The test furthermore helped to determine the grading modulus of the soil which helps to understand the fineness of the soil material (BS1377, 1990). The grading results obtained were used in making computations for proper blending of the local clay soil with activated granite dust. The grading modulus of the soil material was obtained from the formulae;

$$Grading\ modulus = \frac{300-(percentage\ retain\ on\ 2mm+0.425mm+0.075mm}{100} \text{ ….……..Eqn.3.1}$$

c) Atterberg limits test

The test was conducted regarding the guidelines provided by BS 1377: Part 2: 1990 using the method of cone penetration for obtaining the liquid limit, plastic limit by rolling the soil into threads, linear shrinkage and later the plasticity index which was the window showing how the clay material behaved when exposed to moisture (BS, 1990). The purpose of these tests was to determine the plasticity index of the soil to predict the behavior of the soil when it gets in contact with water. The PI informed the workability of the material when molding bricks and their effect to resist shrinkage that could lead to cracking of the bricks (Zhang, 2014).

d) Chemical characterization test

The test was carried out in according to ASTM D8438-23 using the method of XRF spectroscopy. The purpose of this test was to determine the chemical compounds present in the sodium silicate-activated granite dust, which aided in varying the proportions of sodium silicate used to activate the granite dust for formation of a geopolymer, more so in the search for the optimal mix ratio between SS and GD during the activation process (Green brick making manual, 2017).

3.2.2. Physical and chemical properties of granite dust, the chemical properties of sodium silicate and hence the optimal ratio of Granite dust to sodium silicate.

a) Chemical composition test of granite dust

The test was conducted according to ASTM C 114 and the main aim was determine the chemical composition of the granite dust specifically the active elements of alumina, silica, iron oxide, lime (calcium oxide) and magnesium oxide which are active elements needed in brick making (Zhang et al., 2022).

The granite dust was activated with sodium silicate in a proportion of about 22.5:1 and was later exposed to x-rays using an x-ray spectrometer. An x-ray analyzer was then used to capture the fluorescent x-ray signals emitted from the sample, and the signals when analyzed by the x-ray analyzer was used to determine the chemical composition of the sodium silicate-activated granite dust (Zhang et al., 2020).

b) Grading of activated granite dust to a suitable proportion

The test was carried out in reference to the Ministry of Works and Transport's general specification for roads and bridges, using the method of sieve analysis as described by BS 1377 part 2 1990. The purpose of this test was to determine how much of each particle size was present in the GD, and the results were later used for making computations for proper blending with the local clay soil (MoWT, 2005). The sodium silicate-activated granite dust was passed through sieves whose aperture is decreasing with the sieve arrangement of 10, 5, 2, 0.425, 0.075 mm and the pan. The weight retained on each sieve was noted and percentage passing each sieve was calculated. A logarithmic scale graph of percentage pass against sieve sizes was plotted which showed the particle distribution of the granite dust material (MoWT, 2005). Basing on the mass retained on the 2.00, 0.425 and 0.075mm sieves, the grading modulus which informed the fineness of the material was computed from the formulae below.

$$\text{Grading modulus} = \frac{[300-(percentage passing on 2mm+0.425mm+0.075mm)]}{100} \quad \text{.............Eqn. 3.2}$$

c) Compressive strength test for the GD geopolymer

This was done in reference to ASTM C349 through applying a compressive vertical load to the 50*50*50mm cubes made from the sodium silicate-activated granite dust. The test was used to determine the maximum vertical load that the cubes can withstand. (ASTM, 2015).

The test was conducted through obtaining the mix ratios of SS, SH, GD and water, mixed all materials together in the respective ratios, cast the cubes in triplicates of each mix ratio and let to stand for specific maturation dates. The test was conducted on the 7, 14 and 28 days of maturity from which the mix ratio with highest compressive strength was giving light for the optimal mix ratio (Turgut &Algin, 2021).

d) Water absorption test

This test was conducted under the guidelines provided by the cobb method as recorded in EN 1996-2:2006. 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 and also provide a confirmation to the optimal mix ratio was obtained in the compressive strength test (Zhang et al., 2020). The cubes of made of geo-polymerized granite dust at different mix ratios were weighed in air on a weighing scale of three DP precision and weight, W1 recorded was noted. Weighed cubes geo-polymerized granite dust were soaked in water for a period of about 24 hours and weight, W2 was determined using the weighing scale (Maina et al., 2016). All sample mix ratios were in triplicates and the average water absorption capacity of the cubes was obtained from the formulae below.

Water absorption capacity = $\frac{W1-W2}{W1}x100\%$ ....Eqn. 3.3

e) Chemical characterization 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. A portion of prepared sodium silicate was obtained and filtered through the cloth filter to remove any impurities, and exposed to x-rays using an x-ray spectrometer (Zhang et al., 2022).

An x-ray analyzer was used to capture the fluorescent x-ray signals emitted from the sample whereby the signals when analyzed by the x-ray analyzer was used to determine the chemical composition of the granite dust.

3.2.3. Effect of sodium granite dust on the physical, chemical properties and load bearing capacity of unfired clay bricks and determining the best proportion of the dust for the mix to form a composite

3.2.3.1. Mix design for the final brick

This was done through increasing and decreasing of the percentage of sodium silicate-activated granite dust and the clay material by weight until best proportions were achieved. Trial samples were conducted through varying the percentages of activated granite dust and that of the clay material until the best range was achieved where the there was an improvement in the grading of the material. The mix ratios were obtained basing on the densities, grading modulus and the volume of the brick which was to be made of the two major materials (GD and clay) (Singh, 2016).

Blending of clay and granite dust material was done in the established proportions to obtain a material basing on the target mass retained on each sieve suitable for blending the material and come up with well graded material suitable for brick making. The need to ascertain and confirm the best blend of the materials called for the further important physical and chemical tests of compressive strength, water absorption, chemical composition test durability tests, efflorescence test, grading and Atterbag tests on the brick samples various brick physical and chemical tests in order to identify the most suitable mixture by its properties (Mitchell & Soga, 2005).

Basing on the densities of the clay and GD, and the volume of the brick which was to be made (228.6*127.4*76.2mm), the amount of materials required for mixing each brick to make the final brick product was established, molded the bricks and conducted tests of; water absorption capacity, compressive strength, bulk density, efflorescence, and load bearing capacity of the wall panel were carried out in comparison to a control sample as well (Singh, 2016).

a) Molding of bricks

The molding of the bricks was done through preparing a semi dry mix of clay and SS activated GD. The semi dry mix reduces on the extra energy required to crash the clay when it fully dried and hardened. A little water was added to the mixture and molded bricks of $0.00221m^3$, put them on a tarp and air dried them for 28 days

Determined the most suitable mix ratio sample basing on the sample which gave the most positive results of the tests and for this case, the bricks with mix ratio of 51% clay and 49% SS activated GD gave the most positive results from all tests of grading to check for the improvement in the fineness modulus respective to the green brick making manual, Atterbag limits test to check for the improvement of the PI and LS, compressive strength, bulk density, and water absorption capacity, and was taken to be the most suitable mix ratio for brick making. This mix ratio was used to make brick that were used to build a short course wall and tests for load bearing capacity of the wall.

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 and that is 2.61 and 2.72 respectively

(ii) Determined the volume of the brick from;

$$Volume\ of\ brick = 0.2286x0.1274x0.0762 = 2.219x10^{-3}m^3$$

(iii) Determined the volume of clay in the brick sample from;

$$Volume\ per\ centage\ of\ brick\ taken\ up\ by\ clay = Clay\%\ \ x\ volume\ of\ brick$$

(iv) Determined the volume of GD in the brick sample from;

$$Volume\ percentage\ of\ brick\ take\ nup\ by\ GD = GD\%\ x\ volume\ of\ brick$$

(v) Mass of the clay was obtained from the density and respective volume as below;

$$Mass\ of clay = Volumeof clay\ x\ density\ of\ clay$$

(vi) Mass of the GD was obtained from the density and respective volume as below

$$Mass\ of GD = Volume\ of GD\ x\ density\ of granite\ dust$$

(vii) Mass of the SS was obtained from the density and respective volume as below

$$Massof sodium\ silicate = \frac{1}{10}(Massof GD)$$

(viii) Mass of the SH was obtained from the density and respective volume as below

$$Massof sodium\ hydroxide\ solution = \frac{1}{3.5}(Massof sodiumsilicate)$$

3.3.1.2. Test conducted.

The physical and chemical tests were conducted on the SS activated granite dust brick to determine the physical and chemical properties of the brick

a) 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 spectroscopy. The purpose of this test was to determine the improvement of the chemical composition of the clay material after blending it with SS activated granite dust. This was achieved through blending SS activated GD together with the local soils and then expose the mix to the XRF spectrometer to understand the variation of chemical composition in the mixture of local clay soils and sodium silicate-activated granite dust (Olusola & babafemi, 2016)

b) Water absorption test

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 (BS, 2006).

c) Efflorescence test

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 diffusion of soluble salts from the interior of the brick matrix to the surface where they react with atmospheric carbon dioxide to form white patches and also moisture carrying salts from the inside of the brick to the surface (Zhang et al. 2020).

The test was conducted through submerging samples of bricks in cans having water half filled up to the 25mm mark and left the set up to stand for about 24hr. Each time water level fallen below the 25mm mark, water was refilled to maintain the area that was submerged. After 24hr, samples were removed and left to stand for four to 7 days (BS, 2006). The area of efflorescence was calculated, and the exposed face area of the brick was also calculated. The efflorescence was obtained from the formulae.

$$\text{Efflorescence percentage} = \frac{\text{Area of efflorescence}}{\text{Exposed area of brick sides}} x 100\% \quad \text{................Eqn. 3.4}$$

d) Structural load capacity of manufactured unfired clay bricks wall panel

This test was conducted in reference to BS 5628 part 1 1992 and EC 6.

The short wall panel of dimensions 714mm*258.4mm*127.2 mm was subjected to axial loading which kept on increasing until failure was observed.

The modes of failure were monitored and recorded. The crushing force was recorded and further computation done to obtain the load bearing capacity of the wall panel while considering the eccentric forces.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. INTRODUCTION

This chapter entails the tests which was conducted on the local clay soils, granite dust sample from Budondo sub-county, sodium silicate and the tests conducted on the brick made from the blending of the materials. A lot more is done on the analysis of the results and to provide relevant information and insights on the modification of the clay bricks to make unfired clay bricks using sodium silicate activated granite dust.

4.1.1 CLAY SOIL SAMPLE FROM BUDONDO SUB-COUNTY IN JINJA DISTRICT

4.1.1.1. Particle size distribution for clay soils

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 (2017), 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 (Ahbede & Manaseh, 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).

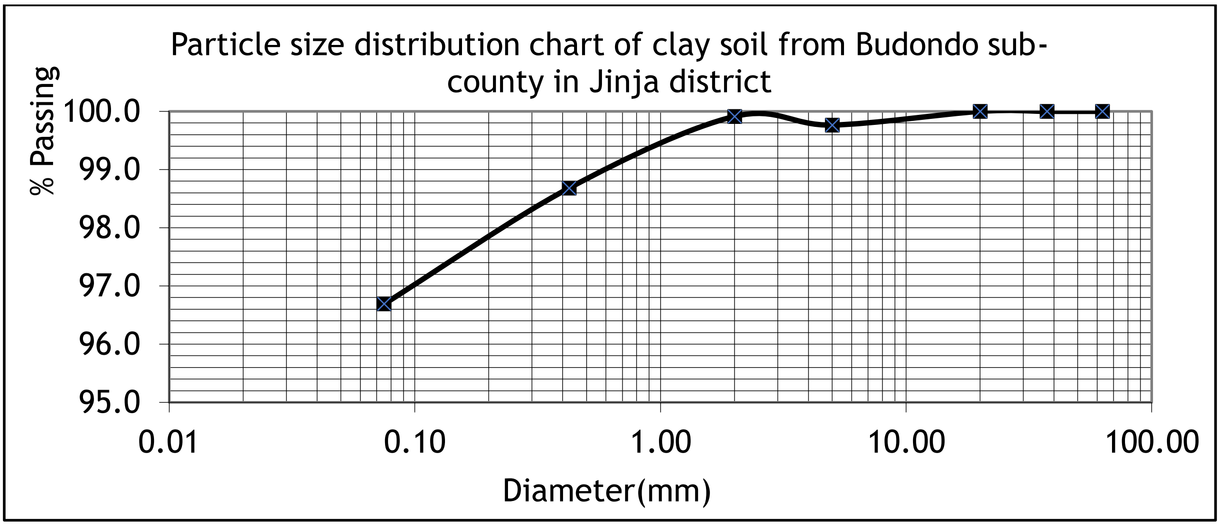


Figure 4. 1: Grading of clay sample from Budondo subcounty

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

Grading modulus = $\frac{[\mathbf{300-(\boldsymbol{percentagepassingon2mm}+0.425\boldsymbol{mm}+0.075\boldsymbol{mm})}]}{\mathbf{100}}$ ....Eqn. 4.1

Grading modulus = $\frac{[\mathbf{300-(99.7+98.4+93.9)}]}{\mathbf{100}} = \mathbf{0.08}$ ....Eqn. 4.2

This grading modulus was interpreted using the criteria in table 4.1.

Table 4. 1: Grading criterion of clay soils

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 number 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).

4.1.1.2. Atterbag limits test for Budondo clay soils

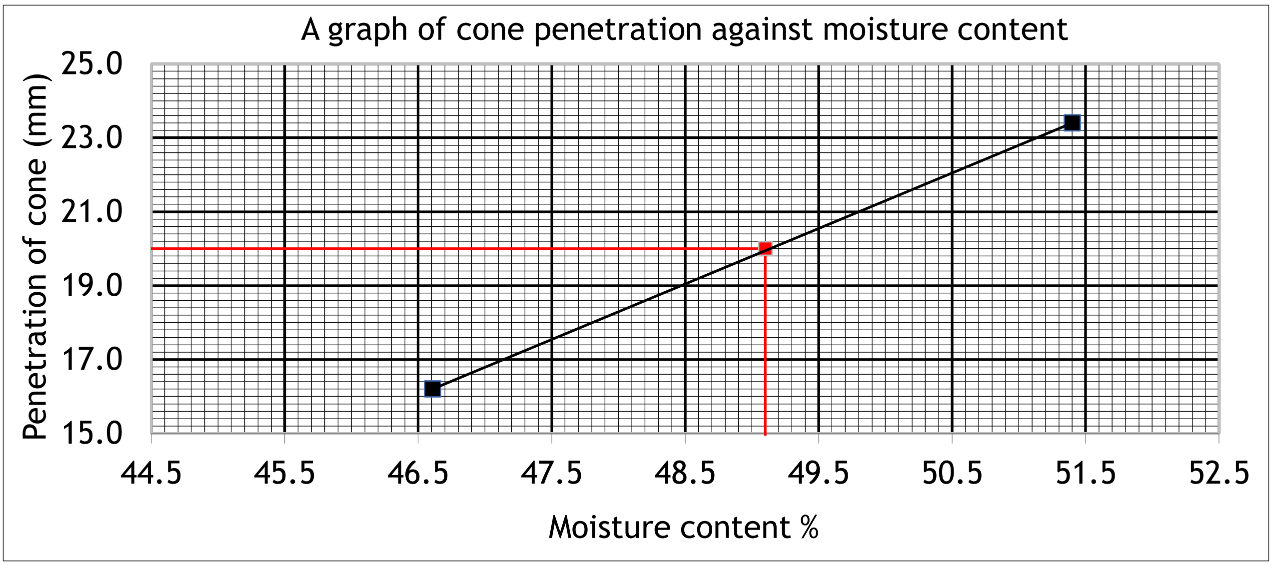


Figure 4. 2: Clay atterbag graphs

From the Atterberg limits test conducted on the clay material, the material had a liquid limit of 48.9% a value which is higher than the maximum liquid limit provided by the green brick making manual this implies that the material has ability to absorb much water and tend to flow easily under self-weight which makes it not desirable for brick making. The plastic limit was found to be 32.1% which informed the difficulty of the clay material in molding and forming of the clay. Basing on the standard of 12 to 22% plastic limit given by green brick making manual (2017), the plastic limit of the clay material (32.1%) is way high and hence a material can have a tendence to lose moisture very first and unevenly hence cracking and breaking of the brick material (Xie et al., 2021). The liquid limit and the plastic limit gave a PI of 16.8% which was the material's property in question. This was the window which was informing the rate of intake of water and change of state form liquid state to plastic state. The larger the window, the higher the intake of water and the poorer the soil material for brick making and vice versa (Singh, 2016). On grading of the clay material basing on its PI, the clay material is medium plastic thus a normal clay. The average linear shrinkage was found to be 10.2%.

According to the Green brick making manual, 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. Hossain et al., (2021), said the liquid limit of a soil sample can be defined as the maximum moisture content at which soil can flow under its own weight such that it passes from plastic state to liquid state, and this is the same moisture content at which the soil also passes from liquid state to plastic state when drying. With the liquid limit of 48.9%, plastic limit of 32.1 and plasticity index of 16.8%, there was need therefore to ensure that the liquid limit of the soil sample was reduced to acceptable standards to prevent this effect.

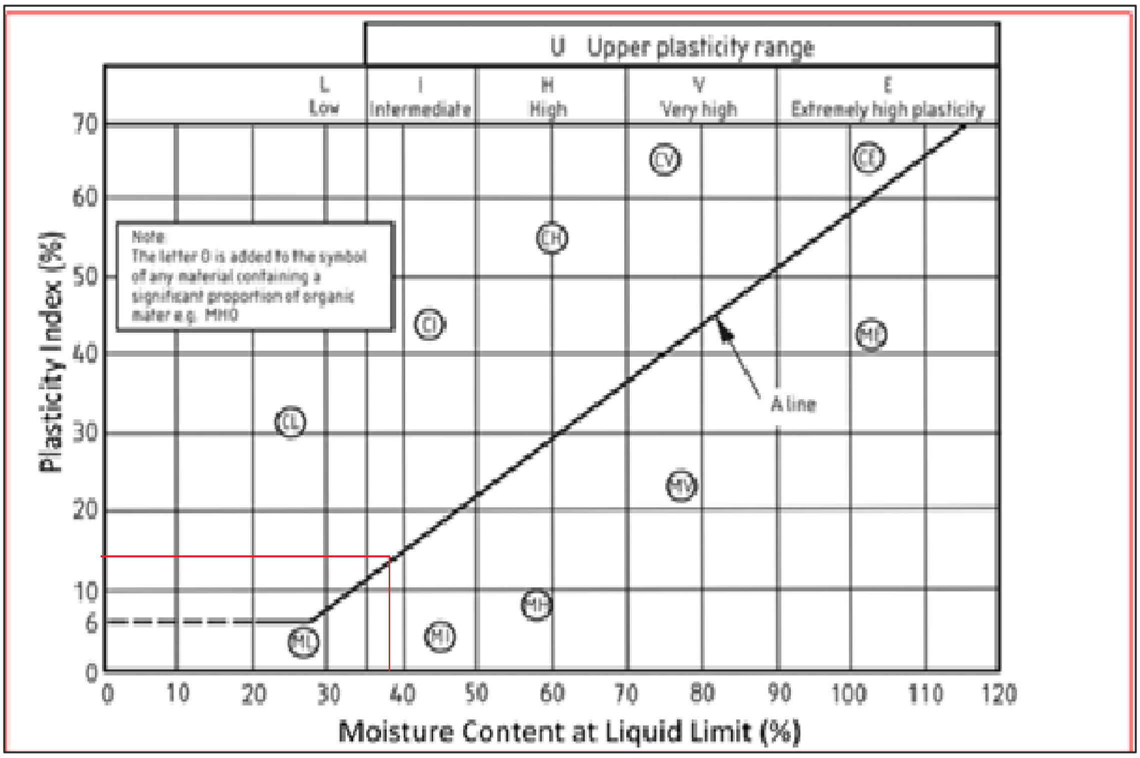


Figure 4. 3: Atterbag limits results on a plasticity chart (Sourced from BS 5930:2015)

The results obtained from the Atterberg limits tests were used to classify the soil using the Unified Soil Classification System (USCS) and the soil was deemed to be an MI which 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).

4.1.1.3. Specific gravity (SG) test for local clay soils (AASHTO T100)

The Specific gravity of the soil is the measure of the material's density relative to the density of water. It is one of the properties of the material that can inform the material's water absorption, compaction and how the particles of the material can be packed for higher density. Materials with lower specific gravity have higher water absorption, lower compaction and lower densities, compared to materials with higher specific gravity (AASHTO, 2020).

The SG of clay is used in the calculation of voids ratio within the material, the porosity of the material and hence the value obtained from the test can inform the water absorption of the material and its compaction.

Table 4. 2: Specific gravity standard ranges

Soil type	Specific gravity ranges	Porosity
Fine sand	2.63-2.67	0.25 – 0.53
silt	2.65-2.7	0.35 – 0.50
Clay and silty clay	2.60-2.9	0.40 – 0.70
Organic soils	Less than 2	-
Granite dust	2.6 – 2.9	0.34 – 0.57

Source: electronic journal for Geo-technical engineering 20(17) 2017

The clay soil from Budondo sub-county had a specific gravity of 2610 which falls within the range for clay soils and silty clay soils. The value of the specific gravity that was obtained informs the porosity of the soil and the and how it can be parked in the material to have a desirable density. With moisture content of 48%, specific gravity of 2610 and dry density of 1600Kg/m^3, the material would have a voids ratio of 0.600 and porosity of 37.5%. This means the clay material is 37.5% having voids filled with air and water and the remaining 62.5% is the solid part of the material. The clay material is in the class of medium porous and can absorb water (Amulya et al., 2021).

4.1.1.4. 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.

Table 4. 3: Key chemical compounds in the clay soil from Budondo subcounty

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

From the results obtained, it was observed the silica and alumina content within the clay soil sample was low. Silica and alumina contents in the clay material are the major chemical components required for brick making as they form the giant molecular three-dimensional network that improves the physical properties of the brick (Zhang et al., 2022). According to the Green brick making manual, the standard value for silica content in clay for brick making should be about 50 to 60% and that for the alumina should be 20 to 30 % to achieve this. This therefore informs the need to improve the chemical composition of the clay material for brick making to prevent the final brick from shrinkage, cracking and warping (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. 4: Chemical suitability of local clay soils from Budondo

Chemical compound	Composition (%)	Required standard	Closest standard	Deviation (%)	Suitability (%)
Silica	10.834	50 – 60	50	78.33	25.85
Alumina	5.705	20 - 30	20	71.48	
Iron oxide	10.201	<7	7	45.73	
Lime	7.070	2 - 5	5	41.40	
Magnesium oxide	4.923	<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.

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

4.2.1. Specific gravity of granite dust

Granite dust was obtained from granite rock tailing in the village of Buwagi Budondo subcounty. The rock quarrying activities are done by MM quarry company Ltd.

Granite dust sourced from this area has a greenish gray color and was found to have a specific gravity of 2.72 and water absorption of 1.8%.

The specific gravity of a material greatly depends on the mineral composition. Materials having minerals that have higher density also have a high specific gravity and those having minerals with lower densities also have lower specific gravity (Klein & Dutrow, 2007). The specific gravity of 2.72 implies the material has ability to improve the density of the clay and make purely densified bricks with high compressive strength and low water absorption, due to the ability to improve on the parking of the material and compaction of the blended material. The lower water absorption of 1.8% informs the material's lower water absorption. Nevertheless, the water absorption helps to improve on the drying time of the clay granite dust blend, faster strength development and balance of the moisture content of the brick material (Xie et al., 2019).

4.2.2. Grading of 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 below. From the grading curve, it was observed that the grading envelope was within the limits of a fine material according to the required standards (Guzlena et al., 2019). This implies that by particle size, the granite dust had a great potential of being suitably incorporated into the clay soil. However, to ascertain the ratio of fine material to the coarse material in order to gauge the material's suitability to increase the fraction of coarse particles in the clay soil, the fineness modulus of the granite dust was established.

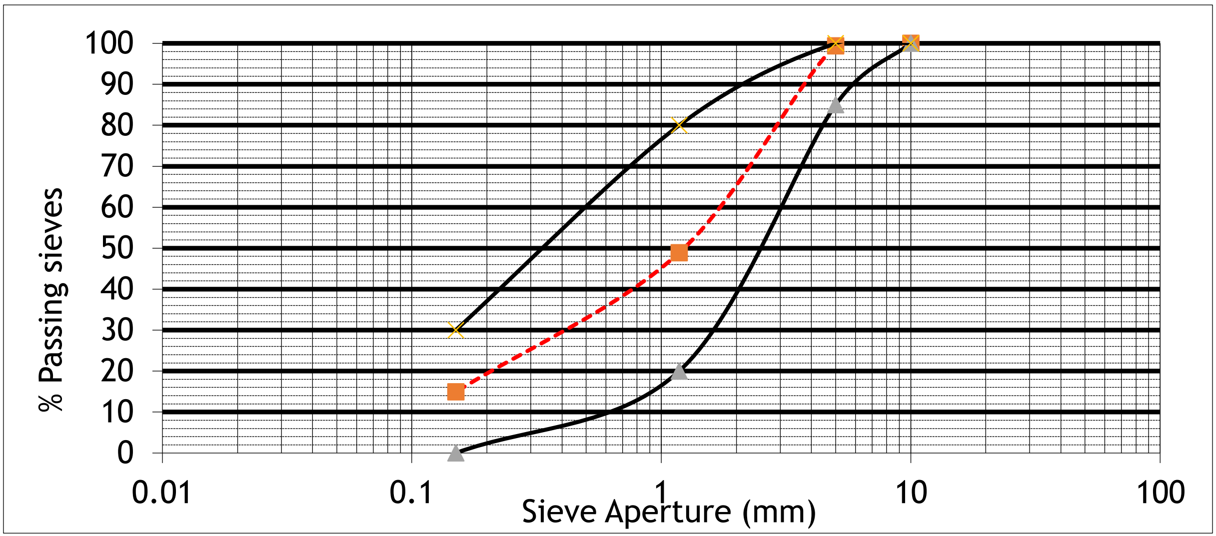


Figure 4. 4: Grading of granite dust

The fineness modulus of the granite dust was obtained using the formula:

Fineness modulus = $\frac{[(percentageretainedon2mm+0.425mm+0.075mm)]}{100}$ ....Eqn. 4.3

Fineness modulus = $\frac{[(0.6+51.1+85.1)]}{100} = 1.368$ ....Eqn. 4.4

Table 4. 5: Recommended specification on granite fines (Sourced from Neolith technical manual)

Grading modulus	Comment
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 number of coarse particles into the final brick matrix (Zhang et al., 2020).

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).

4.2.3. Chemical composition of 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:

Table 4. 6: Key mineral compounds in the granite dust from MM stone quarry in Budondo sub-county

Chemical compound	Composition (%)	Required standard (%)
Silica	**72.301**	**70-77**
Alumina	**14.653**	**11-13**
Iron oxide	**1.732**	**2-3**
Lime	**1.863**	**1-2**
Magnesia	**0.474**	**< 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 below:

Table 4. 7: Suitability of granite dust

Chemical compound	Composition (%)	Required standard	Closest standard	Deviation (%)	Suitability (%)
Silica	72.301	70-77	-	-	94.78
Alumina	14.653	11-13	13	12.72	
Iron oxide	1.732	2-3	2	13.4	
Lime	1.863	1-2	-	-	
Magnesium oxide	0.474	<1	-	-	
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 geo-polymerization reactions in its natural state by chemical composition and that it needed modification in comparison to the required natural pozzolan standards.

4.2.4. Chemical composition of prepared sodium suilicate

The chemical composition of the sodium silicate prepared from the silica fumes was determined using the XRF test and its chemical elements were:

Table 4. 8: 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 represented through modulus control whereby 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).

Below was the modulus of the sodium silicate prepared and how it compared to the recommendations as a natural pozzolan chemical activator:

Table 4. 9: Modulus of sodium silicate

Chemical compound	XRF result (g/l)	XRF results (%)
Silica	98.8	$\left(\frac{98.8}{98.8+76.4}\right)*100\% = 56.4\%$
Sodium	76.4	$\left(\frac{76.4}{98.8+76.4}\right)*100\% = 43.6\%$
Modulus of sodium silicate		$\left(\frac{56.4}{43.6}\right) = 1.29$
Standard modulus (J.L. Provis and J.S.J Van Deventer, 2009		1.0 to 3.0

From the 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.

4.2.5. Compressive strength test of activated granite dust

Table 4. 10: Compressive strength of sodium silicate activated granite dust at 7 days

Trial mix	Average compressive strength (MPa)	GD: SS ratio	Percentage Change in average compressive strength
1	2.86	**6**	**0**
2	3.78	**7**	**32.2**
3	4.99	**8**	**32.0**
4	5.74	**9**	**15.0**
5	4.34	**10**	**24.4**
6	3.29	**11**	**24.2**

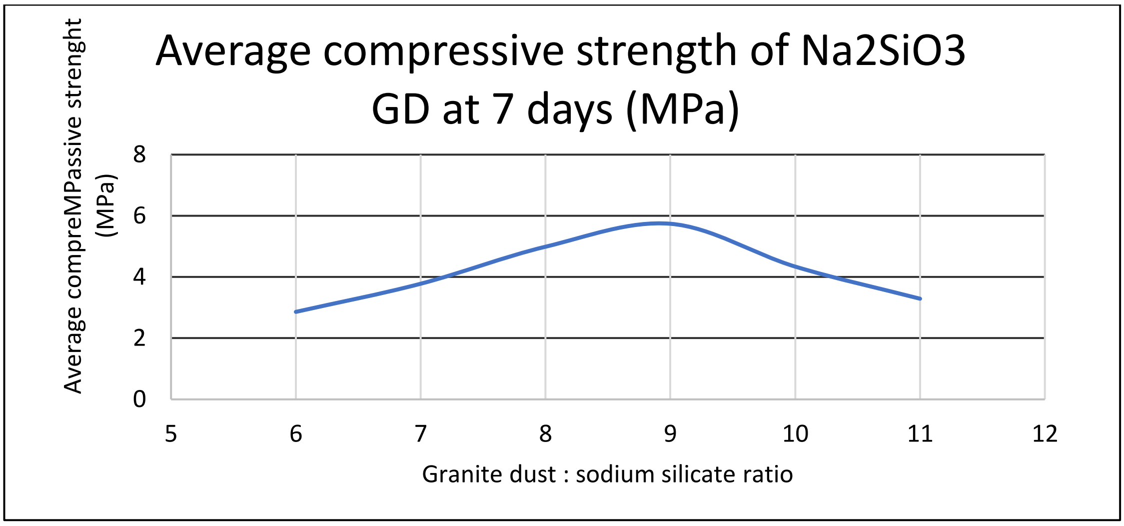


Figure 4. 5: Compressive strength of activated granite dust at 7 days

The compressive strength of sodium silicate activated granite dust mix was tested and found to be increasing by 32.2% when the mix ratio of granite dust was 7: 32% at a ratio of 8 and reached the highest strength of 5.74 MPa at a mix ratio of 9 with a percentage increase of the 15.

The overall increase in the compressive strength up to the highest compressive strength achieved at 7 days was 96% is the positive slope of the curve given by;

$Percentage\ compressive\ strength\ increase = \frac{(5.74-2.86)}{(9-6)} = 0.96$ …………………..Eqn. 4.5

The compressive strength of the activated granite dust mix is dependent of the neutralization chemical reaction existing between the silica and alumina content of the granite dust and sodium silicate (Zhang et al, 2022). At the mix ratio of 6, the compressive strength is low due to excess sodium silicate used in the reaction implying no complete neutralization reaction reached (Zhang et al, 2022). This is because the excess sodium silicate may interact with carbon dioxide and water in air generate sodium carbonate crystals that precipitates on the surface of silica aluminate which lowers the strength and mortar formed hence more sodium silicate remained unreacted and lower bonding of the particles was achieved leading to a low compressive strength.

However, as the granite dust was increased up to the mix ratio of 9, there was a progressive increase in the strength by 96% up to 5.74 MPa indicating a complete neutralization reaction of sodium silicate and granite dust at mix ratio of 9 which led to the formation of sodium aluminate silicate hydrate. The mix ratio presented right proportions of the sodium silicate used. According to Zhang et al, (2022), right proportions of sodium silicate can dissolve, depolymerize and poly-condense the silicate and aluminate oligomers sufficiently to produce –Si-O-Al-O-Si- and –Si-O-Al-O-Si-O-Si- which are cross linked structures in the matrix, making the mortar denser and stronger.

Table 4. 11: compressive strength of sodium silicate activated granite dust mortar at 28 days

Trial mix	Average compressive strength (MPa)	GD: Na2SiO3 ratio	Percentage change in compressive strength
1	6.41	6	0
2	7.58	7	18.3
3	8.96	8	18.2
4	9.74	9	8.7
5	8.24	10	15.4
6	6.97	11	15.4

The compressive strength of the mortar is linearly related to the mix ratios of the activator through the equation; $y = 0.1589x + 6.633$. This gives a linear R-squared value of 0.0568. This value is so small indicating that only 5.7% of the effect of granite dust to sodium silicate ratio is producing the result of the strength of granite dust cubes. This implies that the compressive strength is not only dependent of the granite dust to sodium silicate ratio. There could be other factors curing condition influencing the compressive strength of activated granite dust.

However, the quadratic regression analysis is the best fit for the relationship between compressive strength of activated granite dust and the granite dust to sodium silicate mix ratio.

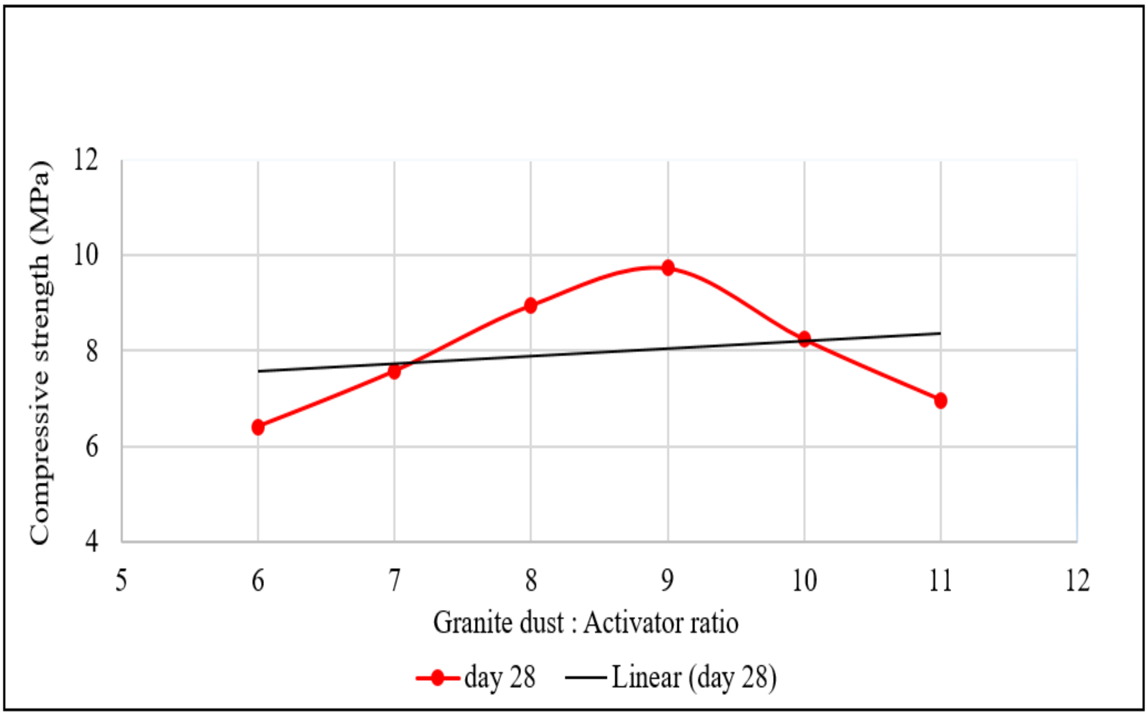


Figure 4. 6: Compressive strength of activated granite dust at 28 days

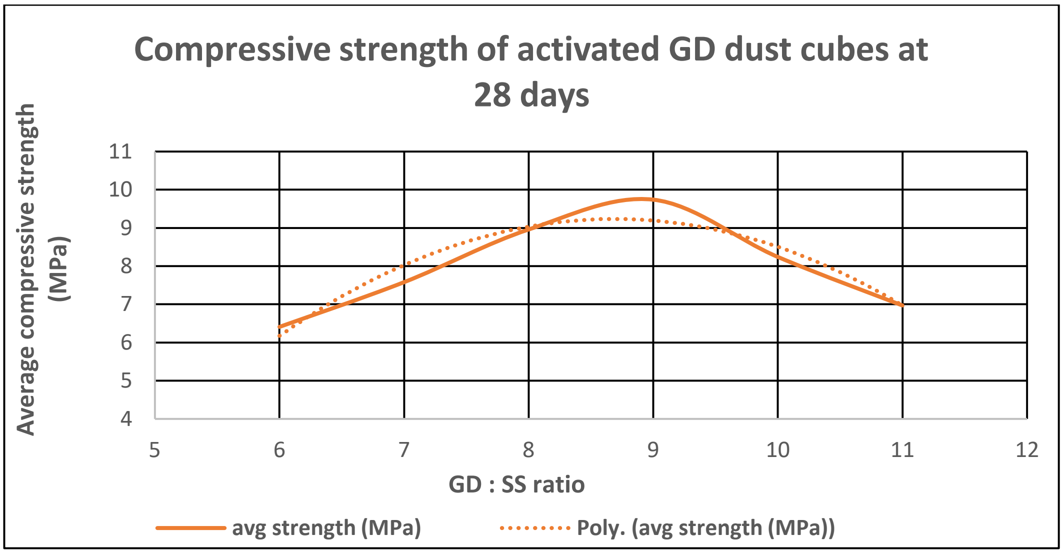


Figure 4. 7: Quadratic regression analysis of compressive strength of GD

For the quadratic regression analysis, the relation of compressive strength is given by the equation $y = -0.4236\ x^2 + 7.3596\ x - 22.735$ with the R- squared value of $R^2 = 0.9188$. The quadratic R-squared value of 0.9188 indicates that 91.9% of sodium silicate is essential for activating granite dust up to a point where the cubes were giving the highest strength of 9.74 MPa. The optimal mix ratio of granite dust to sodium silicate was found to be 8.69 obtained from calculating the vertex of the equation.

$y = -0.4236x^2 + 7.3596x - 22.735$ ....Eqn. 4.6

Optimal mix ratio = $\frac{-b}{2a}$ ....Eqn. 4.7

Optimal mix ratio = $\frac{-7.3596}{2(-0.4236)} = 8.69$ ....Eqn. 4.8

Beyond this mix ratio, sodium silicate was in excess that provided free sodium ions that attracted carbon dioxide and water from the atmosphere, forming carbonates that weakened the bond of the sodium aluminate silicate hydrate hence the progressive reduction in the strength as the ratio was growing bigger.

4.2.6. Water absorption of activated granite dust

Table 4. 12: Water absorption results analysis

Trial mix	Water absorption (%)	GD: SS ratio	Change in water absorption (%)
1	5.8	6	0
2	4.3	7	25
3	3.7	8	14
4	2.4	9	35
5	4.7	10	96
6	6.8	11	45

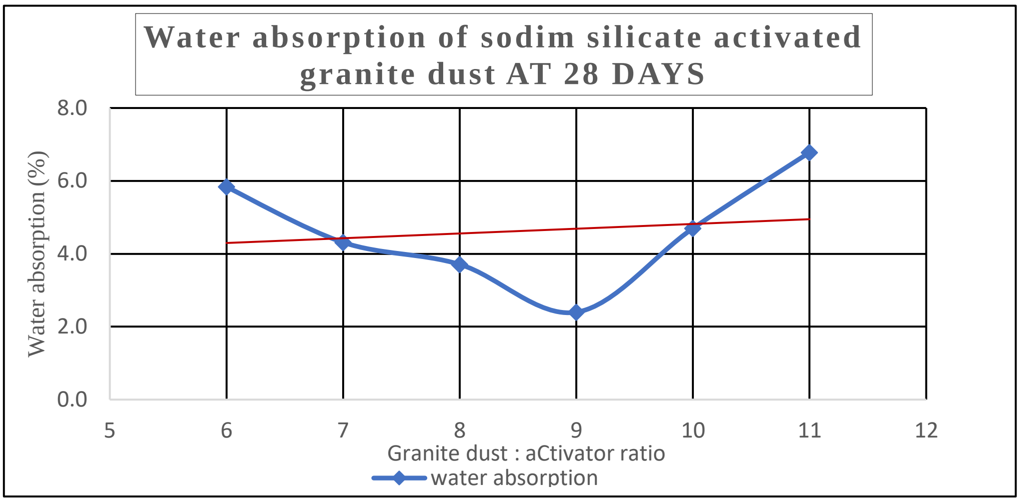


Figure 4. 8: Water absorption of activated granite dust

The water absorption obtained for each set of cubes was below the maximum recommended standard value of 18% with lowest value of water absorption obtained from cubes with granite dust to activator mix ratio of 9. Results shows 25%, 14% and 35% reduction in the water absorption as the mix ratio increase up to mix ratio 9 beyond which the increase in the mix ratio resulted in the 96% and 45% rise in the water absorption up to 6.8% at mix ratio of 11. The 5.8% water absorption at mix ratio of 6 was due to the presence of excess activator in the mix that has affinity to water. As the mix ratio increased, the activator reached the optimal mix ratio and yielded the lowest water absorption. The optimal mix ratio was as a result of complete neutralization reaction leading to formation of giant and dense sodium aluminate silicate hydrate that binds all particles together forming a more stable structure that blocks the micro pores and micro cracks in the lattice of the cube and does not allow penetration of too much water. Beyond the optimal mix, there was little activator available to react with the granite dust and hence the bonding was not so effective yielding higher water absorption results.

Water absorption is linearly related to granite dust to activator ratio following the equation; $y = 0.1589 X + 6.633$ with linear regression R-square value of 0.0568.

This implies there is a very small linear relationship between the water absorption and granite dust to activator mix ratio. The R- square value of 0.0568 indicate only 5.7% dependence of water absorption on the mix ratio of the activated dust however, the quadratic regression analysis explains the relationship very well according to the graph below.

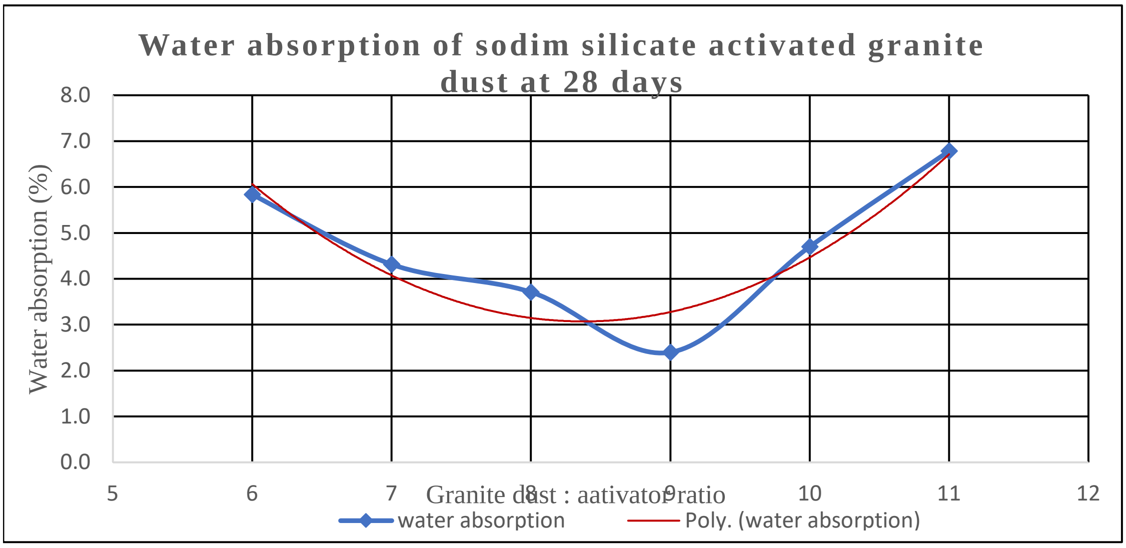


Figure 4. 9: Water absorption analysis using quadratic regression analysis tool

For the quadratic analysis, water absorption correlates to granite dust to activator ratio according to the equation, $y = 0.5295x^2 - 8.8704x + 40.223$ with the R-square value, R^2 = 0.8955, which means 89.6% of water absorption improvement depends on the mix ratio of GD: Activator up to a point of lowest water absorption of 2.4% obtained. This a point of optimal mix beyond which either the activator is in excess giving room to free soluble sodium ion that absorb atmospheric carbon dioxide to form carbonates that affect the strength of the aluminate silicate hydrate formed, or too low level of activator leading to poor bonding.

Optimal mix ratio $= \frac{-b}{2a}$ ....Eqn. 4.9

Optimal mix ratio $= \frac{8.8704}{2 * 0.5295} = \mathbf{8.38}$ ....Eqn. 4.10

The optimal mix ratio obtained from the compressive strength test was 8.68 and the one obtained from water absorption test was 8.38, and the average of the two values give the optimal mix ratio of.

$$\frac{8.68+8.38}{2} = \mathbf{8.53} \text{ .... Eqn. 4.11}$$

Therefore, the optimal mix ratio of granite dust to sodium silicate activator is 8.53

4.3. EFFECT OF SODIUM SILICATE GRANITE DUST ON THE PHYSICAL AND CHEMICAL PROPERTIES OF UNFIRED CLAY BRICKS

4.3.1. Particle size distribution of the SS activated GD and clay blended material (BS 1377 part 2 1990)

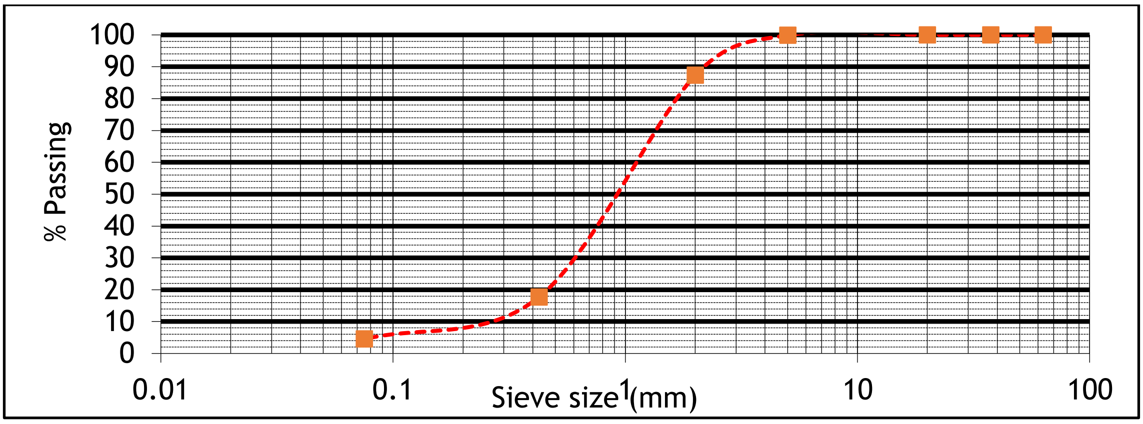


Figure 4. 10: Grading curve for blended material

$$\text{Grading modulus} = \frac{300-(\text{percentage passing on 2mm+0.425mm+0.075mm}}{100} \text{ .... Eqn. 4.12}$$

$$\text{Grading modulus} = \frac{300-(87.3+17.7+4.5}{100} = 1.905 \text{ .... Eqn. 4.13}$$

From the curve of the particle size distribution as seen in figure 6 above, the grading curve indicates well graded material. This implies an improvement in the grading modulus from 0.05 to 1.905 which is a suitable value for the making of bricks.

From the graph, 43.2% passed sieve 200 the separation sieve for the fines which meant a change in the percentage of the silt clay material from 93.9% before blending the clay with activated granite dust the percentage of the course material was found to be 46.4% as that which was to be used in the brick making the percentage course used was obtained from the what passed 2.0mm sieve size and retained on the 0.75mm sieve size, and this makes up both the fine sand and course sand that passed sieve size 2.0mm. From the green brick making manual (2017), the recommended percentage of fine material for brick making should be within the range 25 – 50% and that of course material should be 25 – 45%. The incorporation of activated GD in the clay for brick making led to the improvement of the grade of the clay material from being poorly graded to well graded material basing on the improvement of the grading modulus from 0.05 (fine material) to 1.905 (well graded material) as seen in figure 6 for grading index (Razak et al. (2018). The percentage fines of 43.2 was in the right measure as required for the brick making. However, the percentage course of 46.4 was slightly higher than the recommended course size given in green brick making (2017). The improvement of the grading of the clay soil by the use activated GD implied an introduction of a course material into the clay matrix that helps to contribute to the interlocking of particles in the clay brick matrix as the fines fill up the voids hence making the soil highly suitable brick making (Amulya et al., 2019).

4.3.2. Atterbag limits test for the SS activated GD and clay blended material (BS 1377 part 2 1990)

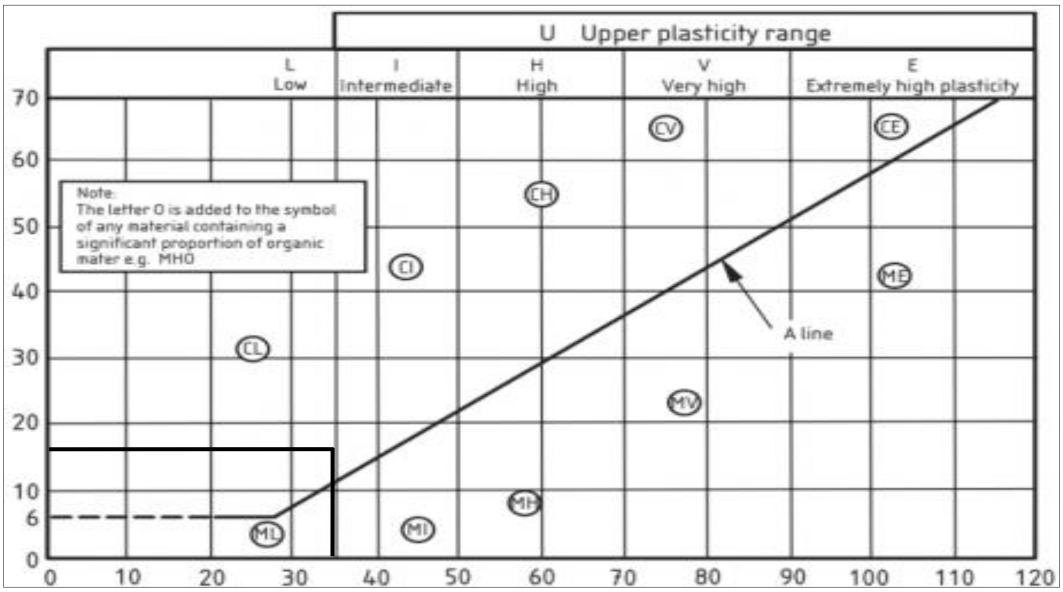


Figure 4. 11: Atterbag limits for blended material

LL = 34.7%

PL = 24.1%

PI = 34.7% - 24.1% = 10.6%

SL = 8.2%

The Atterbag limits test on the blended material was done in accordance to the BS 1377 part 2 1990 and it was found that the blended material had moderate liquid limit of 34.7% which reduced from 48.9% which is the moisture content of the local clay. The Atterbag limits test for the blended material was done in search for the improvement of the neat clay material; to determine how it behaves water is added to it (Xie et al., 2019). The plastic limit also reduced from 32.1% to 24.1 %. the liquid limit reduced by 14.1% and the plastic limit reduced by 8%. The blended material was found to have a plastic index of 10.6% a value that reduced from 16.8 the PI for neat clay soil in Budondo sub-county by 6.2%.

This means the window responsible for the excess intake of water was reduced after blending neat clay soils with activated granite dust.

As the material intake of water reduced through the blending with activated granite dust, a non-plastic material, the swelling properties of the soil was affected such that the material no longer takes in too much water and does not expand which leads to uncontrolled shrinkage and crack leading to the failure of the brick (Zhang et al., 2022). The linear shrinkage limit of the blended material was also reduced to 8.2% from 10.2 which means the material has lost much of its plasticity and so does not over shrink. From figure 7, the blended material has plasticity index graded as low plasticity and this good for brick making since the expanding of the material when wetted has been reduced.

4.3.3. Chemical composition test for the blended material

This test was conducted to determine the chemical boost contributed by SS activated GD to the clay matrix so that the clay material chemical composition conformed to the requirement according to the green brick making manual (2017). The table 17 below shows the chemical composition test as provided by the XRF test.

Table 4. 13: Chemical suitability of the blended material

Chemical compound	Compositions (%)	Standard composition (%)	Closest standard (%)	Deviation (%)	Suitability (%)
Silica	59.07	50 – 60	60	18.14	96.11
Alumina	29.61	20 – 30	30	1.30	
Iron oxide	4.90	<7	-	-	
Lime	2.30	2 – 5	-	-	
Magnesium oxide	0.63	<1	-	-	
Silica: Alumina		2:1			

Basing on the active elements required for brick making, mention; silica, alumina, iron oxide, lime and magnesium oxide percentage composition in the blended material, the material's chemical composition was 96.11% suitable for brick making.

This was based on the mix ratio of 51% clay and 49% activated granite dust. The improvement in the chemical composition to the values recommended by the green brick making manual was due to balanced and complete neutralization reaction that took place after mixing SS, GD and clay leading to the formation of the three-dimensional structure of sodium alumino-silicate hydrate (NASH) that bond the entire clay particles together and hence forms a densified material with closely packed particles and lower voids (Razak et al. (2018).

4.3.4. Efflorescence test for the final SS activated GD unfired clay brick

The efflorescence test was conducted as one of the durability tests to confirm the diffusion of soluble salts to the surface of the brick. This was done through the dipping of the brick into a clear can having distilled water at a 25mm mark and left the test to stand for 24 hours, while adding water each time it was observed to be going below the 25m mark of the can. After 24 hours, the brick was removed the area covered with grayish white patches and the exposed area of the brick was obtained. The efflorescence was obtained from dividing the area of efflorescence by the exposed, and the percentage obtained was compared with standards to determine the grade of the efflorescence foe each test sample as seen in table 13.

Table 4. 14: Efflorescence results for the final bricks materials

Mix proportion (clay & GD%)	Mix label	Average efflorescence	Efflorescence grade
100 and 0	CS	3.075	slight
44 and 56	A	20.240	Moderate
45 and 55	B	15.215	Moderate
46 and 54	C	12.325	Moderate
47 and 53	D	10.645	slight
48 and 52	E	6.149	slight
49 and 51	F	4.218	slight
50 and 50	G	0.485	slight
51 and 49	H	0.000	Nil
52 and 48	L	1.209	slight
53 and 47	J	2.580	slight

$\text{Efflorescence percentage} = \frac{\text{Area of efflorescence}}{\text{Exposed area of brick sides}} x100\%$ .... Eqn. 4.14

The efflorescence test was conducted at the end of 28 days of brick maturity, and it was found that the brick samples with mix ratio 51% clay and 49% SS activated GD were showing no grayish patches on the surface which implied there was no diffusion of the soluble solutes from the brick's matrix to the surface of the brick.

This was attributed to the perfect interlocking of the course particles and filing of the voids provided by the fines in the mix hence densifying the brick and making the brick more intact and compacted such that there were not enough pores for the migration of soluble solutes if they were present (Singh, 2016).

In addition to the proper packing of particles in the brick matrix, the contribution of reactive elements of alumina, silica and sodium form SS, GD and clay material leads to the formation of a three-dimension network of giant sodium alumino-silicate hydrate that bind the particles together. With the ratio of 51% clay and 49% GD, there was sufficiency and balance of reactive elements such that no soluble salts were left unbound (Klein & Dutrow, 2007). These were the common effects accrued to be leading to the variations in the efflorescence grades in the remaining samples which were tested.

4.3.5. Compressive strength of the bricks made from blended material

Compressive strength is one of the primary requirements for the clay masonry units to be used in a specific area. Clay masonry units are regulated by British standard, BS 3921-1985 and BS EN 771-1 among other standards which provides the minimum compressive strength for common bricks to be 5MPa, however, this value applies for the burnt clay brick (BS 3921, 1985). There is no clear standard for unburnt clay bricks, however, for the construction of local common building with lower loading cases and, or self-weight, the compressive strength of 5MPa is okay (BS 3921, 1985). The table below shows various strength requirements for specific structures.

Table 4. 15: Compressive strength of unfired clay bricks made

clay% and GD%	labels	compressive strength			Mix no.
		7 days	14 days	28 days	
100 and 0	CS	1.20	1.42	1.98	0
44 and 56	A	2.43	2.81	3.4	1
45 and 55	B	2.45	2.86	3.490	2
46 and 54	C	2.45	2.99	3.62	3
47 and 53	D	2.60	3.25	3.73	4
48 and 52	E	2.64	3.34	3.88	5
49 and 51	F	2.67	3.87	4.19	6
50 and 50	G	2.68	3.92	4.37	7
51 and 49	H	2.98	4.27	4.92	8
52 and 48	L	2.76	3.77	4.67	9
53 and 47	J	2.65	3.63	4.49	10

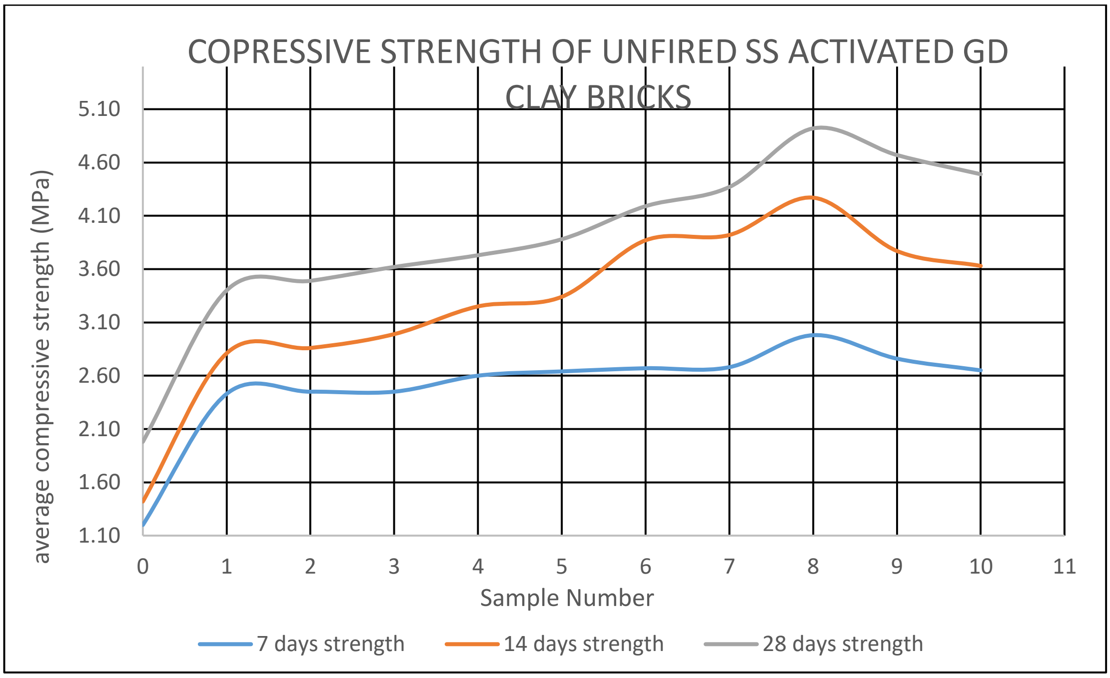


Figure 4. 12: Compressive strength of bricks at 7, 14 and 28 days of maturity

The compressive strength of the unfired clay bricks showed a trend as seen in the graph above. The trend is a result of the synergistic effect of alkali activated granite dust blended with clay material (Zhang, Li & Liu., 2022).

The general trend of the compressive strength over the 7 days, 14 and 28 days show a progressive increase **from** the 1.2MPa control sample to the peak of the strength at 2.98Mpa and then slightly reduces to 2.65MPa at 7^{th} day of maturity of the brick. The same trend is taken by sample at 14 and 28 days of maturity of the bricks. It is noticed that the strength increases as the percentage of the activated granite dust lowers as the percentage of clay increases until the optimum which is obtained with test sample H which is 51% clay and 49% activated granite dust. The point of optimal mix was achieved at the same point with the highest compressive strength which implied proper quantification of material such that the chemical reaction between activated granite dust and clay takes place to completion (Sathonsaowaphak et al., 2021).

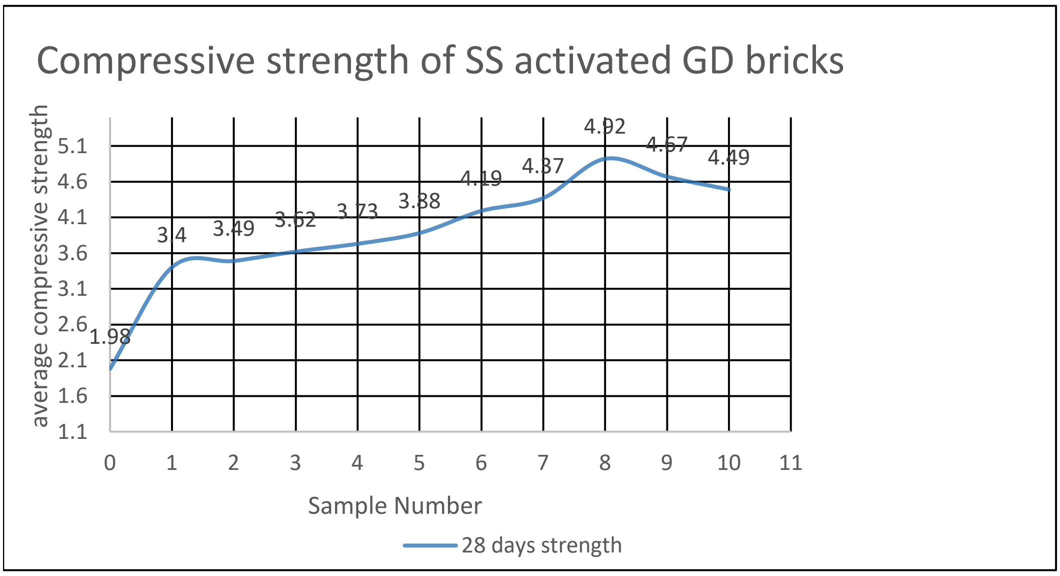


Figure 4. 13: Average compressive strength of SS activated GD bricks

The compressive strength was generally increasing from 1.98MPa which was the control experiment.

The compressive strength of the unfired brick was based on the reaction of the sodium silicate activated granite dust and clay to form giant sodium alumino-silicate hydrate compound that is a cementitious gel that binds the particle in the brick matric tightly together and lowers the micro voids to below 20%, which makes the brick be more resistant to compressive forces (Zhang, 2024).

From CS which had 100% clay and 0% sodium silicate activated GD, the strength was low at 1.98MPa which is 3.02MPa less than the standard value and 71.7% below the compressive strength of sample 1 which is 44% clay and 56% sodium silicate activated granite dust. This is due to the failure of clay cohesive forces to bind the particles tightly together and resist the compression higher than 1.98MPa (). After the addition of activated granite dust, the compressive strength increased by 71.7% at sample A, 76.3, 82.8, 88.4, 95.9, 111.6, and 120.7% for samples B, C, D, E, F, and G with 45% and 55%, 46% and 54%, 47% and 53%, 48% and 52%, 49% and 51%, and 50% and 50% clay and activated granite dust respectively. This is due the progressive neutralization reaction between sodium silicate activated granite dust and clay minerals leading to formation of stable giant sodium alumino-silicate hydrate (Heath et al., 2009). At 8 which sample H, the compressive strength reached its maximum of 4.92 MPa with a percentage strength increase of at this point there was complete neutralization reaction as there was sufficient 148.5%. elements reacting to form the giant stable sodium alumino-silicate hydrate and there were no excess elements that could render the reaction passive (Heath et al., 2009). However, the clay material increased further as activated sodium silicate activated granite dust was reducing, the compressive strength slightly reduced as seen at 9 and 10 for L and J with percentage strength reduction of 5.1% and 8.7% respectively. This was due to the presence of insufficient alkali activated granite dust to react with excess alumino-silicate in the clay hence the formation of weaker bonds and the drop in the strength (Sathonsaowaphak et al., 2021).

Strength and the mix ratios of clay and activated granite dust. The R-squared value showed that the compressive strength was 79.8% dependent of the mix ratio of activated granite dust and clay with the best proportion shown at 8 where X = (51% clay and 49% activated granite dust)

4.3.6. Water absorption test of the SS activated GD clay bricks

The water absorption of the brick is one of the durability tests which have to be checked to confirm the resistivity of the brick to the capillary raise of water, as well as any form of wetting. This was conducted in respect to EN771-1 using distilled water of density 1000kg/m^{3}at a temperature of 25^{o}C, and this was conducted through testing brick test samples of different mix ratios at 7days, 14 days and 28days of brick maturity (Sathonsaowaphak et al., 2021). When testing for the water absorption of the brick, there was a reduction in the water absorption from the control sample CS to 1, 2, 3, 4, 5, 6, 7 and minimum water absorption of 13. 75 % was seen at sample 8 from which the water absorption started to increase at sample 9 and 10 after which progressive increase in the clay and reduction of the SS activated GD percentages would only result to progressive increase in the water absorption (Zhang & Liu, 2022). Table 11 below gives the percentage reduction in the water absorption for every mix sample that was tested. It should be noted that the reduction in the water percentage is due to the close packing of the particles favored by the interlocking of the course material and filling of the voids by the finer material in the clay brick matrix, up to a mix ratio when there is a perfect balance of the clay and activated GD and perfect packing of particles, reducing the voids ratio and hence lowering the capillary raise of water in the brick matrix (Xie et al., 2019).

Table 4. 16: Decrement in water absorption of SS activated GD bricks

Mix number	Water absorption (%)			Water absorption decrement at 28 days maturity
	7 days	14 days	28 days	
Control	22.09	20.11	19.99	0.00
1	19.93	19.32	17.54	12.26
2	19.02	17.89	16.73	4.62
3	18.04	17.32	16.62	0.66
4	17.58	17.14	16.00	3.73
5	17.42	16.73	15.78	1.38
6	17.31	15.92	14.81	6.14
7	16.95	15.76	14.46	2.36
8	16.58	15.22	13.75	4.91
9	16.89	16.16	14.62	-6.33
10	17.99	16.52	14.97	-2.39

At points where the clay material was increasing beyond 51%, there was an increase in the water absorption due to presence of too much fines in the brick and this leads to the increases in the voids ratio and poor packing of material, low compaction which results in the escalated capillary raise of water through the micro pores in the brick matrix (Sathonsaowaphak et al., 2021).

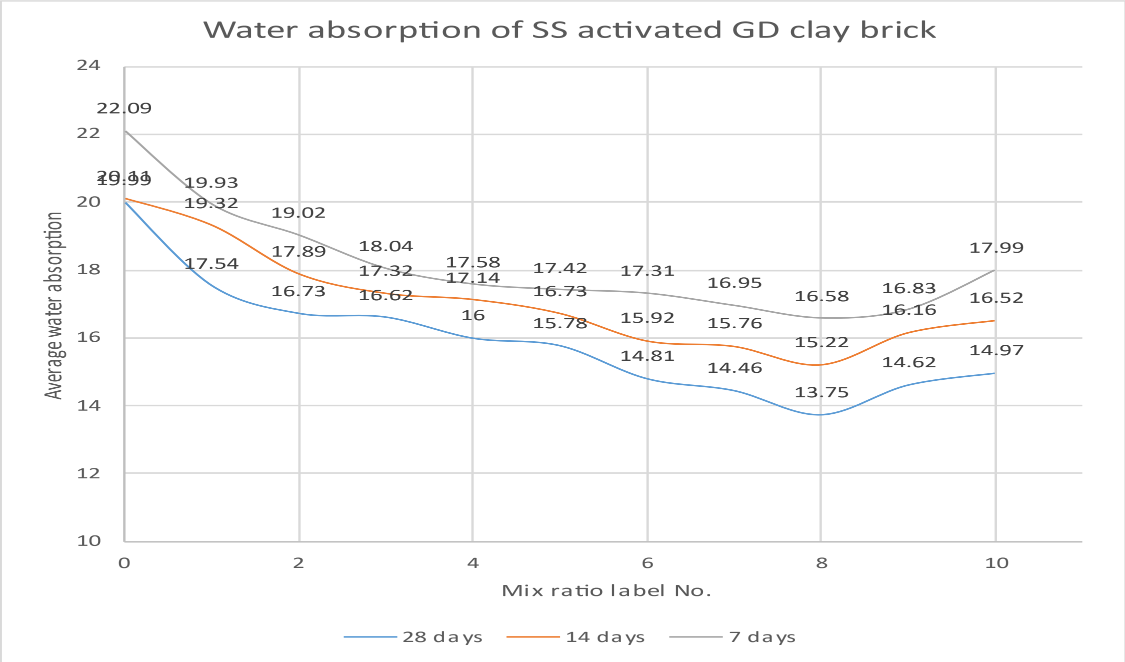


Figure 4. 14: Water absorption of the final brick at 7, 14 1nd 28 days of maturity

4.3.7. Load bearing capacity of the short three wall course

The load bearing capacity was conducted with respect to BS 5628 part 1 1992 and Euro code 6 (EN 1996.1.1.,2005). A short three course wall of thickness 127.2mm and length 714mm height of 258.6mm was built using general purpose mortar of strength 2.5 Mpa, unfired SS activated GD bricks of compressive strength 4.92MPa as obtained from the best optimal mix ratio. The perpends and beds were 15mm. The bearing capacity of the wall was found to be 138.96KN.

On considering the eccentric factor since the loading of the walls are not perfectly vertical, load distribution 194.6 KN/m which was within the range for walls which can be used for low-cost buildings, external walls on light buildings and non-load bearing buildings for important structures (BS, 1992). The wall panel was subjected to the loading until failure and the only mode of failure noticed was cracking whereby the mortar was seen cracking and then the bricks developed diagonal cracks.

The table 4. 16 below shows the load bearing capacity achievement. The brick wall panel made from unfired bricks without SS activated GD had a bearing capacity of 77.1KN and so only good for non-load bearing walls (EN1996, 2005).

Table 4. 17: Load bearing capacity of brick wall panel

Element	Unfired SS activated GD clay brick wall panel	Wall panel from unfired clay bricks without SS activated GD
Brick compressive strength (Mpa)	4.92	1.98
Masonry compressive strength (MPa)	1.95	1.08
Wall area (mm^2)	90820.8	90820.1
Crushing force (KN)	118.1	65.4
Eccentricity, e (mm)	21.2	21.2
Reduction factor **Φ**	0.667	0.667
Effective stress (KN/mm^2)	1.53	0.849
Bearing capacity (KN)	138.96	77.1

4.4. Brick drawing

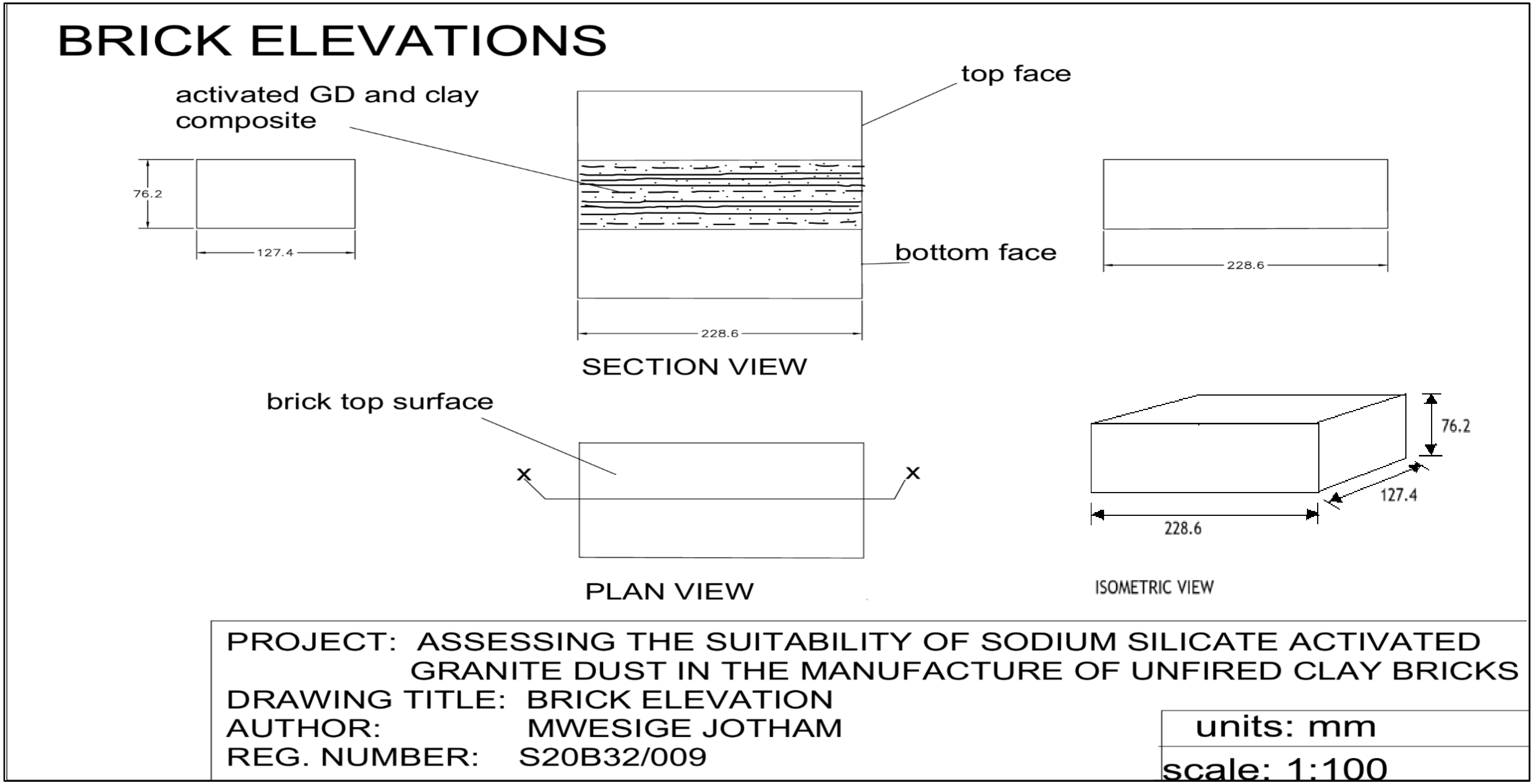


Figure 4. 15: Brick elevations

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The clay material had a grading modulus of 0.08 which meant a very fine material, a PI of 16.8%, LS of 10.2%, SG of 2.61 and 25.87% suitable for brick making basing on the chemical composition test by XRF spectrometer. The clay material was found to be CL soil with medium plasticity and very fine particles with layered structure of silica to alumina in the ratio of 1:2. The material has ability to take in water and expand, and on shrinking it cracks and not suitable for bricking making.

The physical and chemical properties of granite dust sourced from MM quarry company Ltd showed the FM of 1.368 which means the material was generally fine grained. The material had a SG of 2.72 and water absorption of 1.87% which meant a higher density and so can be greatly improve the density of brick and lower porosity. The material also had ability to maintain moisture content when mixed with clay. The active elements needed for brick making (alumina, silica, iron oxide, lime and magnesia) present in the granite dust contributed to 94.78% suitable for pozzolanic activities and geo-polymerization. This implies GD can be used as a pozzolan and can be geo-polymerized. The sodium silicate that was used to activate GD had 98.8g/l silica content and 76.4g/l sodium. A good pozzolan should have higher concentration of silica content. SS had a modulus of 1.29 which is a suitable value for the use of the material as an activator (Provis & Deventer., 2009). after activating the GD with SS, the cubes made in search of the optimal mix ratio for geo-polymerization, had a compressive strength of 9.74MPa and lowest water absorption of 2.4%, which was got from the sample with mix ratio of 9:1 (GD: SS), with the ratio of sodium silicate to sodium hydroxide to water that was used to in preparing the activator was 2.5:1:0.4 (SS: SS: H_2O).

The mix design for the final brick was established basing grading SG results for both the clay and activated GD, and the volume of the brick.

The brick had a volume of 0.00221m^3 with dimensions 228.6*127.4*76.2mm. Individual masses required for molding a single brick was determined and found out that 2.954kg, 2.957kg, 0.296kg and 0.085kg of clay, GD, SS and sodium hydroxide respectively were mixed to make a single optimized brick in the ratio 51% clay to 49% activated granite dust. The brick made had a density of 1828.62kg/m^3, bulk density of 1814kg/m^3, compressive strength of 4.92MPa, water absorption of 13.75%, free from efflorescence and can be used to make walls with load bearing capacity of 138.96KN hence a good brick for external walls but not for high raiding buildings and high loading structures.

5.2. Recommendations

1. further study should be conducted on the most appropriate curing measure of the geopolymer stabilized bricks to ensure proper strength development and improvement of other physical properties
2. Find out the behavior of other pozzolans and incorporate them in the modification of clay for unfired brick making. Different geopolymers have different unique characteristics and various conditions like temperature.

REFERENCES

1. Harriet et al., (2021), Investigating Why Burnt Brick Making is Not Carried out in BudondoSub-county, Jinja District (Uganda).
2. Raj, A. et al. (2023) 'Building a Sustainable Future from Theory to Practice: A Comprehensive PRISMA-Guided Assessment of Compressed Stabilized Earth Blocks (CSEB) for Construction Applications', Sustainability, 15(12), p.9374. Available at: https://doi.org/10.3390/su15129374.
3. P, Turgut & H, M, Algin, (2021), Limestone dust and wood sawdust as brick material.
4. Arasa, F.O., Onchiri, R. and Abiero-Gariy, Z.C. (2021) 'Experimental Investigation on the Compressive Strength and Durability Performance of Modified Dry-Stack Hollow Sandcrete Blocks', OALib, 08(12), pp. 1–13. Available at: https://doi.org/10.4236/oalib.1108216.
5. EN 1996-2:2006. Eurocode 6 Design of Masonry Structures–Part 2: Design Considerations, Selection of Materials and execution of Masonry. British Standards Institution; London, UK: 2006.
6. Singh, S. et al. (2024) 'Large CO2 reduction and enhanced thermal performance of agro-forestry, construction and demolition waste-based fly ash bricks for sustainable construction', Scientific Reports, 14(1), p. 8368. Available at: https://doi.org/10.1038/s41598-024-59012-8.
7. Joshi, E. (2023) 'A Review: Application of Granite Quarry Waste in Brick Manufacturing', International Journal of Advances in Engineering and Management (IJAEM), 5, p. 181. Available at: https://doi.org/10.35629/5252-0510181183.
8. Tang, C.-S. et al. (2022) 'Investigation on microstructure evolution of clayey soils: A review focusing on wetting/drying process', Journal of Rock Mechanics and

Geotechnical Engineering, 15(1), pp. 269-284. Available at: https://doi.org/10.1016/j.jrmge.2022.02.004.

9. Amulya, G., Moghal, A.A.B. and Almajed, A. (2021) ‘A State-of-the-Art Review on Suitability of Granite Dust as a Sustainable Additive for Geotechnical Applications’, Crystals, 11(12), pp. 1526. Available at: https://doi.org/10.3390/cryst11121526.

10. Mitchell, J. K., & Soga, K. (2005). *Fundamentals of Soil Behavior* (3rd ed.). Wiley-Interscience. DOI: 10.1002/9781118211031.

11. Davidovits, J. (2015). Geopolymer Chemistry and Applications. 4th ed. Saint-Quentin, France: Geopolymer Institute.

12. Ghosh, P. (2019). Geopolymers: A New Material for Sustainable Construction. Journal of Materials Science and Engineering, 8(2), pp. 123-134.

13. Kumar, S., Singh, S. and Mathur, S. (2017). Granite Dust Based Geopolymer as a Sustainable Construction Material. Construction and Building Materials, 142, pp. 40-50.

14. 14. Maina, S., Muigai, R. and Mwangi, I. (2016). Performance of Interlocking Stabilized Soil Blocks in Rural Construction Projects. Journal of Civil Engineering and Construction Technology, 7(3), pp. 45-52.

15. Palomo, A., Krivenko, P. and Garcia-Lodeiro, I. (2014). Alkali-Activated Materials: Advances in Sustainable Construction. London: Springer.

16. Razak, H.A., Chik, Z. and Aris, A. (2018). Sustainable Development in Construction: The Role of Local Materials. In: Proceedings of the International Conference on Civil Engineering and Sustainable Development, Kuala Lumpur, pp. 104-110.

17. Walker, P. and Stace, T. (2017). Compressed Earth Blocks: Design and Construction. Earthscan, pp. 56-70.

18. Xie, Z., Tang, Y. and Zhang, L. (2018). A Review on Geopolymer Materials for Construction Applications. Construction Materials, 54, pp. 89-103.

19. Klein, C., & Dutrow, B. (2007). Introduction to mineralogy. Manual of mineral science. John Wiley & Sons. Nesse, W. D. (2012). Oxford University Press.

20. Zhang, Y., Li, H. and Wang, J. (2020). Sodium Silicate-Activated Geopolymer: A New Class of Construction Materials. Journal of Building Materials Research, 46(6), pp. 95-102.

21. Kumar, S., Bhardwaj, S., and Mathur, V. (2017). Clay Characterization for Brick-Making Quality: An Analytical Study. Journal of Civil Engineering and Architecture, 12(6), pp. 123-134.

22. Fattah, M. Y., Fathi, M., and Kamal, R. (2019). Engineering Properties of Brick-Making Clays. Construction Materials, 9(4), pp. 245-255.

23. Amulya,G.,Moghal,A.A.B.and Almajed,A.,2021. A State-of-the-Art Review on Suitability of Granite Dust as a Sustainable Additive for Geotechnical Applications. Crystals,11(12),p.1526.

24. Andrade, F.A., Al-Qureshi, H.A. and Hotza, D., 2011. Measuring the plasticity of clays:A review. Applied Clay Science, 51(1-2), pp.1–7.

25. Castillo, H. et al., 2022. State of the art of geopolymers: A review. e-Polymers, 22(1), pp.108–124.

26. Chindaprasirt, P. et al., 2012. Effect of SiO2 and Al2O3 on the setting and hardening of high calcium fly ash-based geopolymer systems. Journal of Materials Science, 47(12), pp. 4876–4883.

27. Kang, Y. et al., 2024. Detrital and authigenic clay minerals in shales: A review on their identification and applications. Heliyon,10(20),p.e39239.

28. Lachheb, Y., Youssef, A. and Younsi, Z., 2023. Unfired clay bricks: A sustainable alternative for construction. Journal of Sustainable Building Materials, 15(3), pp. 95–109.

29. Medina, G. et al., 2017. Mineralogical study of granite waste in a pozzolan/Ca(OH)2 system: Influence of the activation process. Applied Clay Science, 135, pp. 362-371.

30. Phoo-ngernkham, T. et al., 2015. Effects of sodium hydroxide and sodium silicate solutions on compressive and shear bond strengths of FA-GBFS geopolymer. Construction and Building Materials,91,pp.1–8.

31. Olusola, K. O., and A. J. Babafemi. "Effect of Granite Dust on the Properties of Laterized Earth Blocks." *Journal of King Saud University-Engineering Sciences* 28, no. 1 (2016): 104-111

32. Polakowski, C. et al., 2021. Particle Size Distribution of Various Soil Materials Measured by Laser Diffraction—The Problem of Reproducibility. Minerals, 11(5), p. 465.

33. Vieira, C.M.F., Sánchez, R. and Monteiro, S.N., 2008. Characteristics of clays and properties of building ceramics in the state of Rio de Janeiro, Brazil. Construction and Building Materials, 22(5), pp. 781–787.

34. **Sathonsaowaphak, A., Chindaprasirt, P. and Pimraksa, K., 2021.** Strength and durability of alkali-activated clay bricks. *Materials Today: Proceedings*, **47**, pp.345-356. Available

35. Heath, A., Lawrence, M., Walker, P. and Fourie, C., 2009. Compressive strength and microstructural analysis of unfired clay masonry bricks. *Engineering Geology*, 109(3-4), pp.169-176. Available at: https://www.sciencedirect.com/science/article/pii/S0013795209002063

36. Heath, A., Walker, P., Fourie, C. and Lawrence, M., 2009. Engineering properties of unfired clay masonry bricks. *Engineering Geology*, 107(3-4), pp.144-152. Available at: https://www.sciencedirect.com/science/article/pii/S0013795209001197

APPENDIX A: TABLES OF RESULTS AND QUANTIFICATION

Table 1: Masses of individual constituents required to make a single brick

		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

Table 2: 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

Table 3: porosity ranges

Porosity	meaning
<25	Low porosity
25 – 39	Medium porosity
>40	High porosity

Source: Hydro-geologic properties of Earth Materials and principles of groundwater flow

Table 4: Summary of lab results and the standard value

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
	Chemical	Silica	10.834	50 to60
		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
Granite Dust	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

Table 5: Classes of bricks

Brick class	Strength (N/m^2)	usage
Engineering bricks A	70	High load resistance structures
Engineering bricks B	50	Load bearing structural members
Dump proof course 1	5	Foundation works and outside walls
Dump proof course 2	5	Foundation works and outside walls
Normal burnt bricks	5	Non load bearing structural members
Air-dried bricks	-	Low-cost buildings

Source: Specification for bricks BS 3921 1985 pp5

Table 6: Summary of laboratory results for the brick

Property	Test results
Grading modulus	1.905
Plasticity index	10.6%
Chemical suitability	96.11%
Compressive strength	4.9Mpa
Bulk density	1814kg/m^3
Water absorption	13.75%
Efflorescence	0.00 (nil)
Load bearing capacity	138.96KN

APPENDIX B: PHOTOS DURING LABORATORY WORK

Figure 1: Sampling of granite dust

Figure 2: Sampling of clay soils from Budondo

Figure 3: Grading of samples by sieve analysis

Figure 4: Mixing of granite dust with sodium silicate

Figure 5: Casting of activated granite dust cubes

Figure 7: Mixing activated GD with clay for brick making

Figure 6: Crashing of the partially hardened clay sample

APPENDIX C: LABORATORY RESULTS

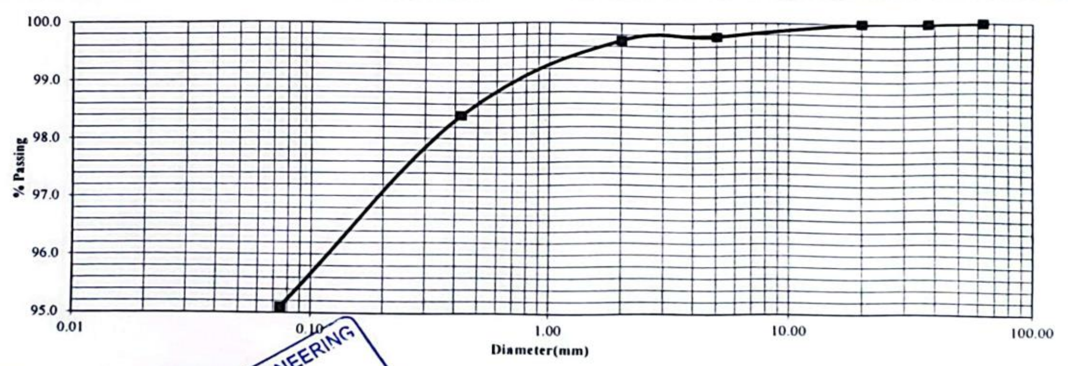
INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MWESIGE JOTHAM AND KAKANDE HANNINGTON	Stirling

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. Refernece 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

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	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
Total fines	4899.5	95.1			
Bottom Pan	11.3				
Extracted fines	4888.2				
Total sample	5154.6				
Grading Modulus		**0.07**			



FOR TESTING LAB

Lab Technician	*Materials Engineer*

STIRLING CIVIL ENGINEERING LTD
BOX 796, KAMPALA (U)

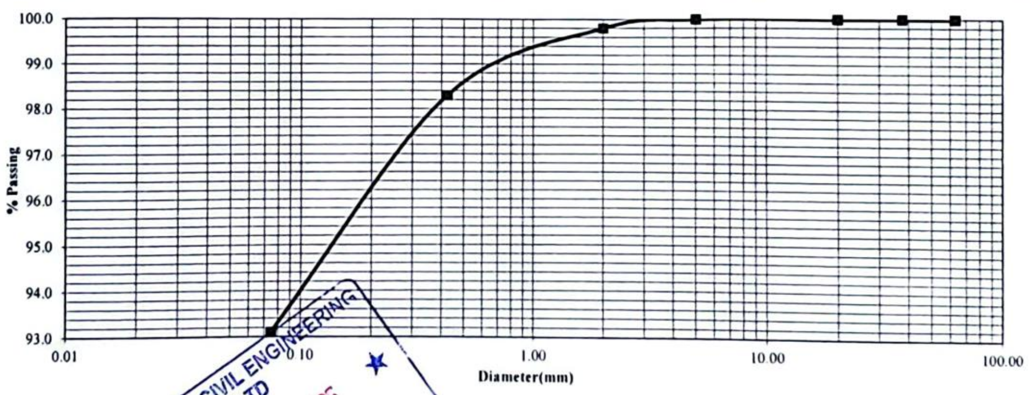
INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MWESIGE JOTHAM AND KAKANDE HANNINGTON	Stirling

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. Refernece 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	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	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
Total fines	4650.1	93.1			
Bottom Pan	12.9				
Extracted fines	4624.2				
Total sample	4984.0				
Grading Modulus		**0.09**			



FOR TESTING LAB

Lab Technician *Materials Engineer*

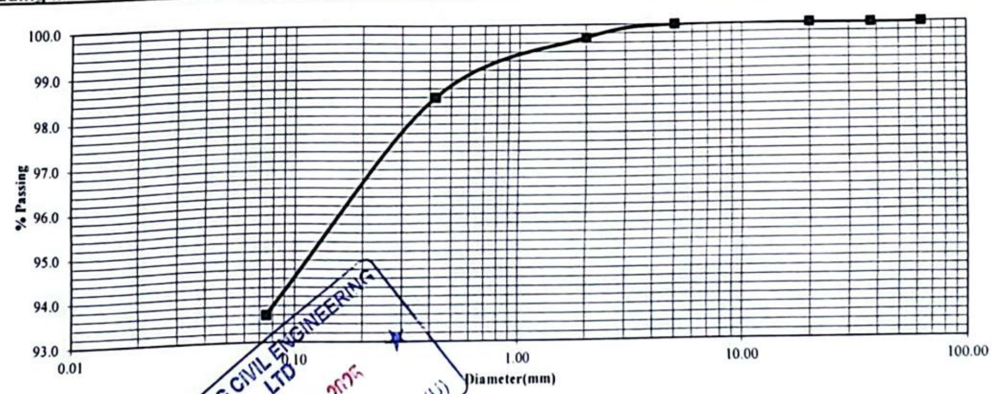
STIRLING CIVIL ENGINEERING LTD
FEB 2025
P.O. BOX ... 796, KAMPALA (U)

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

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. Refernece 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
Total fines	4712.5	93.6			
Bottom Pan	13.0				
Extracted fines	4699.5				
Total sample	5031.9				
Grading Modulus		**0.08**			



FOR TESTING LAB

Lab Technician Materials Engineer

INSTITUTION	CLIENT	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MWESIGE JOTHAM AND KAKANDE HANNINGTON	Stirling

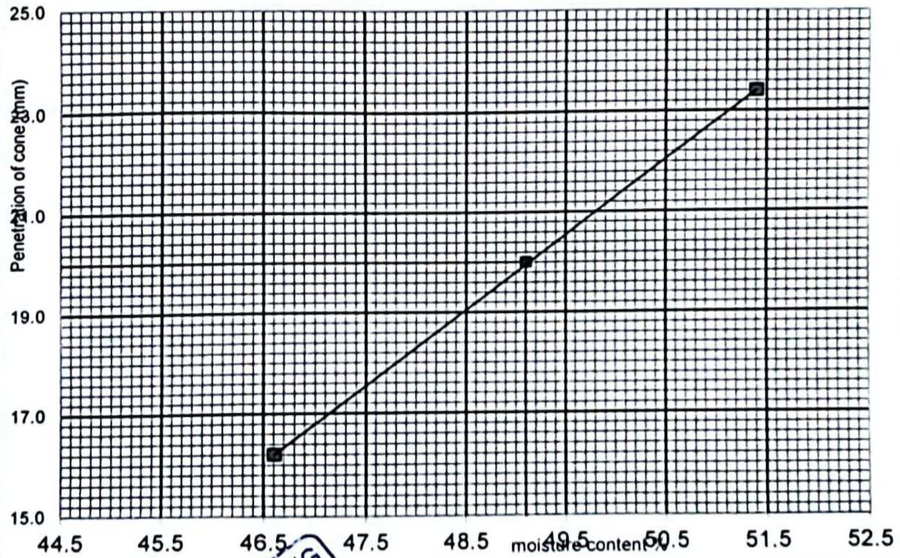
PROJECT	ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS

ATTERBERG LIMITS BS 1377 PART 2:~~5~~.4-1990

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		

CONE PENETRATION METHOD

		Liquid limit (%)								Plastic Limit
LIQUID LIMIT	Test No	1		2		3		4		(%)
Initial dail gauge reading	mm	0		0		0		0		
Final dail 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

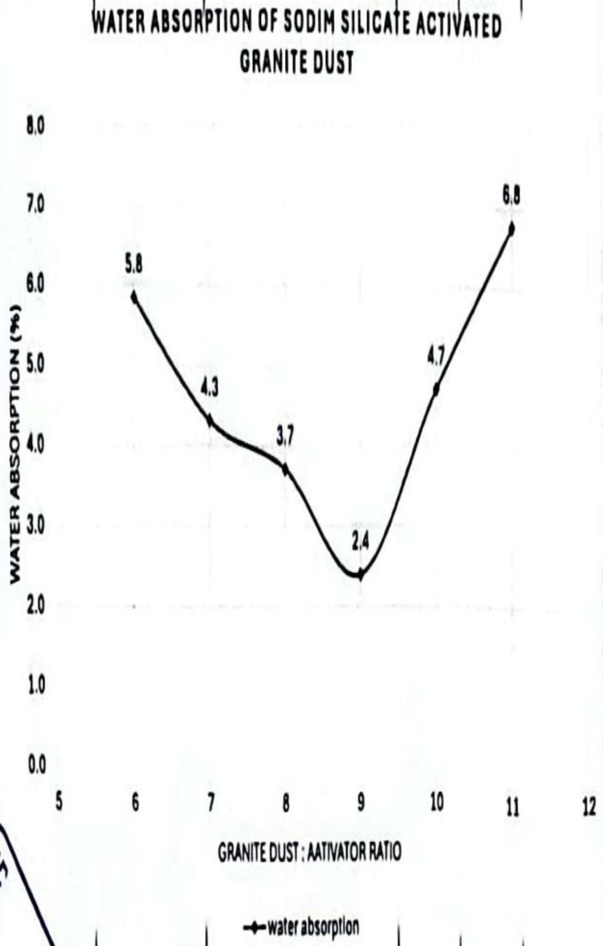


Liquid limit%	49.1
Plastic Limit %	32.3
Plasticity Index %	16.8
Reference:	

LINEAR SHRINKAGE	1	2	Average Shrinkage
Initial length Lo (mm)	14	14	
Oven dried length Ld(mm)	12.6	12.5	
Linear shrinkage 100x(1-Ld/Lo) (%)	10.0	10.7	10.4

For contractor	For consultant
[signature; stamp: STIRLING CIVIL ENGINEERING LTD ... BOX 796, KAMPALA (U)]	

					bulk density (kg/m3)	2.7



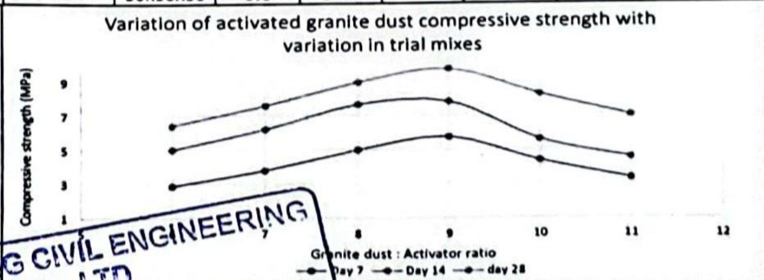
TESTING LAB			CLIENT	
LAB Technician	Materials engineer		MWESIGE JOTHAM	KAKANDE HANNINGTON

STIRLING CIVIL ENGINEERING LTD
11 FEB 2025
P.O. BOX 796, KAMPALA (U)

INSTITUTION	CLIENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MWESIGE JOTHAM AND KAKANDE HANNINGTON	Stirling

PROJECT	ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS
Test	Determination of the compressive strength of pozzolan cement mortar cubes
Location	Granite dust from MM stone quarry in Budondo sub county in Jinja district
Structure	Geopolymer mortars to be used for the manufacture of unburnt clay bricks
Sodium silicate : Sodium hydroxide : Water	2.5 : 1 : 0.4

Trial mix	Casting date	Testing date	Cube dimension (mm)	Weight (kg)	Density (kg/m^3)	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	6
			50x50x50	0.27	2160		12.6	5.03		
	21-Dec-24	18-Jan-25	50x50x50	0.3	2400	28	15.7	6.26	6.41	6
			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	7
			50x50x50	0.3	2400		16	6.41		
	21-Dec-24	18-Jan-25	50x50x50	0.3	2400	28	18.7	7.47	7.58	7
			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	8
			50x50x50	0.29	2320		19.1	7.65		
	21-Dec-24	18-Jan-25	50x50x50	0.3	2400	28	22.3	8.92	8.96	8
			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	9
			50x50x50	0.27	2160		19.4	7.76		
	21-Dec-24	18-Jan-25	50x50x50	0.3	2400	28	24.4	9.77	9.74	9
			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	10
			50x50x50	0.29	2320		13.8	5.53		
	21-Dec-24	18-Jan-25	50x50x50	0.3	2400	28	20.7	8.29	8.24	10
			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	11
			50x50x50	0.3	2400		11.2	4.49		
	21-Dec-24	18-Jan-25	50x50x50	0.28	2240	28	17.6	7.05	6.97	11
			50x50x50	0.3	2400		17.2	6.89		



STIRLING CIVIL ENGINEERING LTD

TESTING LAB		CLIENT:	
LAB Technician	Materials engineer	Mwesige Jotham	Kakande Hannington

Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
Email: dgal@mia.go.ug
Website: www.mia.go.ug

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

THE REPUBLIC OF UGANDA

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

DFD 014/2025
29th 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 20th January 2025, and analysed on 24th 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
Elemental Composition		
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.

Fred. 29/01/25
Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
Email: dgal@mia.go.ug
Website: www.mia.go.ug

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

THE REPUBLIC OF UGANDA

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

DFD 052/2025
14th 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 04th March 2025, and analysed on 12th 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

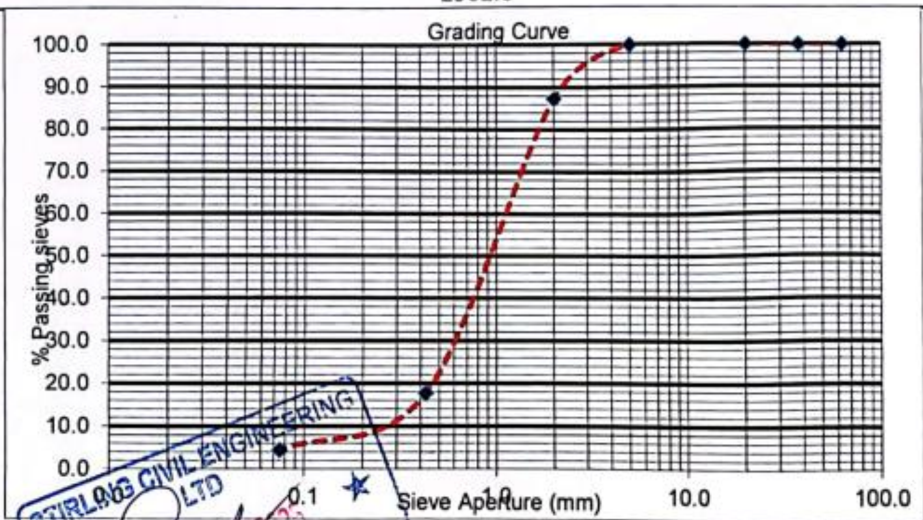
Remarks
1. Results relate to sample analyzed and are reported as on received basis.

14/03/25
Semalago Fredrick
Government Analyst

INSTITUTION	CLIENT	CONTRACTOR

INSTITUTION	CLIENT	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MWESIGE JOTHAM KAKANDE HANNINGTON	Stirling Stirling Civil Engineering Ltd

PROJECT	FINAL YEAR RESEARCH AND DESIGN PROJECT			
GRADING FOR CLAY AND GRANITE DUST BLENDED MATERIAL (BS 1377-2, 1990)				
		SAMPLE No.	DRY WT. BEFORE	DRY WT. AFTER
LOCATION:	subcounty	B	5048.7	2902.6
MATERIAL DESCRIPTION:	CLAY MATERIAL BLENDED WITH GRANITE DUST		DATE SAMPLED:	14/12/2024
			DATE TESTED:	2-Feb-25
MAXIMUM SIEVE SIZE (mm)	WEIGHT RETAINED	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	0.3	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			
WIEGHT LOST DURING SIEVING	0			
TOTAL	2902.6			
		2902.6		



STIRLING CIVIL ENGINEERING LTD
P.O. BOX 7..., KAMPALA (U)

MATERIAL ENGINEER		Students MWESIGE JOTHAM KAKANDE HANNINGTON

INSTITUTION	CLIENT	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY	MWESIGE JOTHAM AND KAKANDE HANNINGTON	Stirling

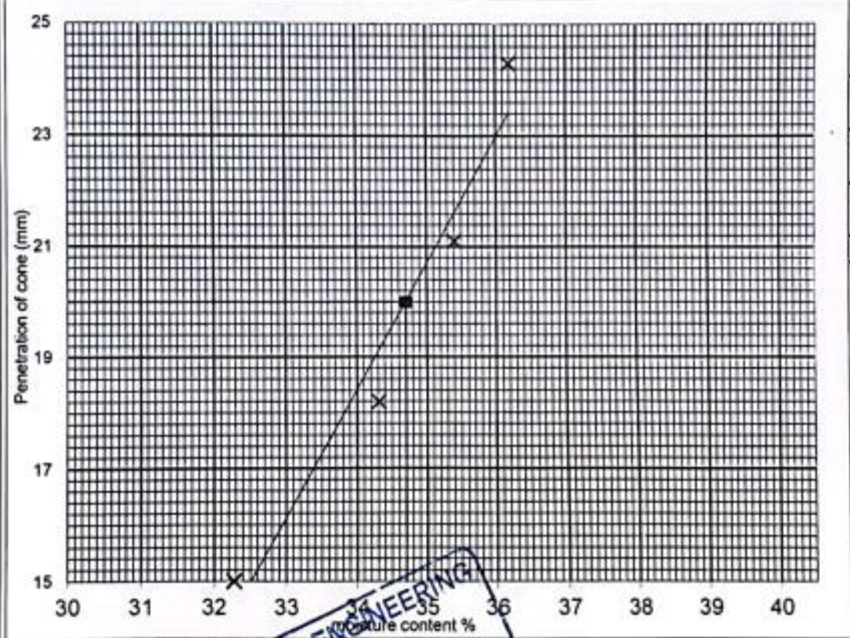
PROJECT	ASSESSING THE SUITABILITY OF SODIUM SILICATE-ACTIVATED GRANITE DUST IN THE MANUFACTURING OF UNFIRED CLAY BRICKS

ATTERBERG LIMITS BS 1377 PART 2:5:4-1990

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		

CONE PENETRATION METHOD

		Liquid limit (%)								Plastic Limit	
LIQUID LIMIT	Test No	1		2		3		4		(%)	
Initial dail gauge reading	mm	0		0		0		0			
Final dail Gauge reading	mm	15		18.2		21.1		24.3			
Average penetration	mm	16.6						22.7			
Container No.		BE	KO	BE	PI46	PIV6	PI38	PIQE	PI52		
Mass of wet soil +container	g	50.60	50.10	53.00	52.05	58.21	57.03	53.61	52.07	43.63	42.31
Mass of dry soil +container	g	39.97	39.56	41.22	40.59	44.66	44.12	41.09	40.29	36.55	35.42
Mass of container	g	7.02	6.92	6.94	7.14	6.95	7.10	7.07	7.18	7.05	7
Mass of moisture	g	10.6	10.5	11.8	11.5	13.6	12.9	12.5	11.8	7.1	6.9
Mass of dry soil	g	33.0	32.6	34.3	33.5	37.7	37.0	34.0	33.1	29.5	28.4
Moisture content	%	32.3	32.3	34.4	34.3	35.9	34.9	36.8	35.6	24.0	24.2
Average Moisture content	%	32.3		34.3		35.4		36.2		24.1	



Liquid limit%	34.7
Plastic Limit %	24.1
Plasticity Index %	10.6
Reference:	

LINEAR SHRINKAGE	1	2	Average Shrinkage
Initial length Lo (mm)	14	14	
Oven dried length Ld(mm)	12.9	12.8	
Linear shrinkage 100x(1-Ld/Lo) (%)	7.9	8.6	8.2

	STUDENT
MATERIAL ENGINEER	MWESIGE JOTHAM KAKANDE HANNINGTON

INSTITUTION	CLIENT	LABORATORY
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MWESIGE JOTHAM KAKANDE HANNINGTON	Stirling

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/m³)	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	J1	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	

STIRLING CIVIL ENGINEERING LTD P.O. BOX 796, KAMPALA (U) Material engineer	Students Mwesige Jotham Kakande Hannington

INSTITUTION	CLIENT	LABORATORY
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MWESIGE JOTHAM KAKANDE HANNINGTON	Stirling
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	14 days

Clay % & GD %	Mix no.	Label	Dimension (mm)	Weight (kg)	Density (kg/m³)	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	10	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	

STIRLING CIVIL ENGINEERING LTD
KAMPALA (U)

Material engineer

Students

INSTITUTION	CLIENT	LABORATORY
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MWESIGE JOTHAM KAKANDE HANNINGTON	Stirling
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	28 days	

Clay % & GD %	Mix no.	Label	Dimension (mm)	Weight (kg)	Density (kg/m^3)	Crushing load (kN)	Compressive strength (MPa)	Avg. (MPa)
100 and 0	Control	CS1	228.0X127.0X75.8	3.55	1613.87	57.62	1.99	1.98
		CS2	228.0X127.1X75.9	3.558	1611.28	57.09	1.97	
44 and 56	1	A1	228.3X126.9X76.0	3.658	1661.36	94.18	3.25	3.40
		A2	228.5X126.9X76.0	3.66	1660.81	105.25	3.63	
45 and 55	2	B1	228.4X126.8X76.1	3.695	1676.54	102.81	3.55	3.49
		B2	228.6X126.8X76.2	3.683	1667.44	99.42	3.43	
46 and 54	3	C1	228.3X126.8X75.8	3.69	1681.64	108.27	3.74	3.62
		C2	228.4X126.9X75.9	3.717	1689.64	101.44	3.50	
47 and 53	4	D1	228.6X127.0X76.1	3.725	1688.23	107.71	3.71	3.73
		D2	228.3X126.9X75.9	3.735	1698.56	108.64	3.75	
48 and 52	5	E1	228.4X126.8X76.1	3.728	1691.52	114.40	3.94	3.88
		E2	228.5X126.7X75.8	3.721	1695.62	110.01	3.80	
49 and 51	6	F1	228.3X126.9X75.9	3.794	1725.39	115.31	3.98	4.19
		F2	228.4X126.9X75.8	3.785	1722.82	127.24	4.39	
50 and 50	7	G1	228.5X126.8X75.6	3.79	1730.26	121.69	4.20	4.37
		G2	228.6X126.5X75.5	3.785	1733.61	130.99	4.53	
51 and 49	8	H1	228.2X126.5X75.6	3.998	1831.96	140.30	4.86	4.92
		H2	228.3X126.8X75.8	3.992	1819.27	143.87	4.97	
52 and 48	9	L1	228.5X126.9X76.0	3.988	1809.65	136.28	4.70	4.67
		L2	228.5X126.8X75.9	3.984	1811.64	134.44	4.64	
53 and 47	10	J1	228.4X126.9X76.1	3.988	1808.06	130.72	4.51	4.49
		J2	228.6X126.8x75.8	3.980	1812.78	129.57	4.47	

STIRLING CIVIL ENGINEERING LTD
P. O. BOX 736, KAMPALA (U)

Material engineer

Students

Mwesige Jotham   Kakande Hannington

INSTITUTION		STUDENTS	LABORATORY
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa		MWESIGE JOTHAM KAKANDE HANNINGTON	Stirling
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^3)		2.601	2.625
Avg SG (g/cm^3)		2.610	
SG (kg/m^3)		2610	

STIRLING CIVIL ENGINEERING LTD
P.O. BOX 796, KAMPALA (U)

Material engineer

Students

Mwesige Jotham   Kakande Hannington

INSTITUTION	STUDENTS	LABORATORY
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MWESIGE JOTHAM KAKANDE HANNINGTON	Stirling
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^3)	2.725	2.716
Avg SG (g/cm^3)	2.720	
SG (kg/m^3)	2720	
Water absorption (%)	1.87	1.77
Avg water absorption (%)	1.82	
STIRLING CIVIL ENGINEERING LTD P.O. BOX 796, KAMPALA (U) Material engineer		Students Mwesige Jotham Kakande Hannington

INSTITUTION	STUDENTS	LABORATORY
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MWESIGE JOTHAM KAKANDE HANNINGTON	Stirling
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^2)	Area of efflorescence (mm^2)	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	H1	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		

STIRLING CIVIL ENGINEERING LTD
2 MAR 2025
P.O. BOX ... KAMPALA (U)

Material engineer

Students

Mwesige Jotham   Kakande Hannington

INSTITUTION	STUDENTS	LABORATORY
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MWESIGE JOTHAM KAKANDE HANNINGTON	Stirling

PROJECT	ASSESSING THE SUITABILITY OF SODIUM SILICSTE ACTIVATED GRANITE DUST IN THE MANUFACTURE OF UNFIRED CLAY BRICK		
TEST	WATER ABSORPTION TEST	CAST DATE	4/Feb/2025
LOCATION	BUDONDO SUB-COUNTY	TEST DATE	5/ Mar/2025
SAMPLE DESCRIPTION	UNFIRED BRICKS MADE FROM BLENDING ACTIVATED GRANITE DUST AND CLAY SOIL	TEMPERATURE(°C)	24
MASS OF MATERIAL	AGE (days) 7	DENSITY OF WATER	1000KG/m³

Clay % and GD %	Trial mix	label	Air dry (g)	SSD (g)	Weight in water (g)	Bulk density (kg/m³)	Water absorption (%)	Average water absorption (%)
100 and 0	Control	CS1	3571	3984	1611	1505	21.96	22.09
		CS2	3572	3986	1605	1500	22.22	
44 and 56	1	A1	3678	3995	1601	1536	19.91	19.93
		A2	3677	3998	1605	1537	19.94	
45 and 55	2	B1	3711	3997	1606	1552	19.86	19.02
		B2	3703	3998	1602	1545	18.02	
46 and 54	3	C1	3718	3996	1615	1562	18.06	18.04
		C2	3737	3981	1609	1575	17.45	
47 and 53	4	D1	3733	3940	1611	1603	17.71	17.58
		D2	3754	3897	1571	1614	17.45	
48 and 52	5	E1	3747	3892	1604	1638	17.62	17.42
		E2	3748	3886	1586	1630	17.21	
49 and 51	6	F1	3796	3918	1607	1643	17.72	17.31
		F2	3798	3891	1603	1660	16.90	
50 and 50	7	G1	3799	3887	1620	1676	16.92	16.95
		G2	3797	3880	1623	1682	16.62	
51 and 49	8	H1	3891	3888	1655	1742	16.98	16.58
		H2	3842	3880	1660	1731	16.54	
52 and 48	9	L1	3847	3887	1620	1697	17.10	16.83
		L2	3856	3895	1625	1699	16.56	
53 and 47	10	J1	3839	3893	1613	1684	17.98	17.99
		J2	3859	3890	1600	1685	17.99	

STIRLING CIVIL ENGINEERING LTD
P. O. BOX 796, KAMPALA (U)

MATERIAL ENGINEER

STUDENTS

MWESIGE JOTHAM KAKANDE HANNINGTON

INSTITUTION	STUDENTS	LABORATORY
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MWESIGE JOTHAM KAKANDE HANNINGTON	Stirling

PROJECT	ASSESSING THE SUITABILITY OF SODIUM SILICSTE ACTIVATED GRANITE DUST IN THE MANUFACTURE OF UNFIRED CLAY BRICK		
TEST	WATER ABSORPTION TEST	CAST DATE	4/Feb/2025
LOCATION	BUDONDO SUB-COUNTY	TEST DATE	5/ Mar/2025
SAMPLE DESCRIPTION	UNFIRED BRICKS MADE FROM BLENDING ACTIVATED GRANITE DUST AND CLAY SOIL	TEMPERATURE(°C)	24
MASS OF MATERIAL	AGE (days) 14	DENSITY OF WATER	$1000KG/m^3$

Clay % and GD %	Trial mix	label	Air dry (g)	SSD (g)	Weight in water (g)	Bulk density (kg/m^3)	Water absorption (%)	Average water absorption (%)
100 and 0	Control	CS1	3557	3985	1611	1498	20.11	20.11
		CS2	3563	3988	1605	1495	20.10	
44 and 56	1	A1	3662	3975	1613	1550	18.43	19.32
		A2	3669	3980	1621	1555	18.93	
45 and 55	2	B1	3704	3999	1625	1560	19.70	17.89
		B2	3695	3991	1628	1564	17.42	
46 and 54	3	C1	3710	3899	1615	1624	17.43	17.32
		C2	3728	3885	1614	1642	17.21	
47 and 53	4	D1	3729	3895	1618	1638	16.39	17.14
		D2	3741	3885	1626	1656	17.88	
48 and 52	5	E1	3739	3897	1625	1646	16.61	16.73
		E2	3733	3881	1627	1656	16.85	
49 and 51	6	F1	3741	3921	1716	1697	16.43	15.92
		F2	3796	3895	1629	1675	15.26	
50 and 50	7	G1	3798	3890	1620	1673	15.37	15.76
		G2	3791	3885	1623	1676	16.15	
51 and 49	8	H1	3885	3893	1727	1794	15.10	15.22
		H2	3831	3884	1725	1774	15.34	
52 and 48	9	L1	3838	3892	1700	1751	16.00	16.16
		L2	3841	3899	1701	1747	16.32	
53 and 47	10	J1	3823	3898	1713	1750	16.83	16.52
		J2	3846	3896	1705	1755	16.21	

STIRLING CIVIL ENGINEERING LTD
P. O. BOX ... KAMPALA (U)

MATERIAL ENGINEER

STUDENTS

MWESIGE JOTHAM KAKANDE HANNINGTON

INSTITUTION	STUDENTS	LABORATORY
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MWESIGE JOTHAM KAKANDE HANNINGTON	Stirling

PROJECT	ASSESSING THE SUITABILITY OF SODIUM SILICSTE ACTIVATED GRANITE DUST IN THE MANUFACTURE OF UNFIRED CLAY BRICK		
TEST	WATER ABSORPTION TEST	CAST DATE	4/Feb/2025
LOCATION	BUDONDO SUB-COUNTY	TEST DATE	5/ Mar/2025
SAMPLE DESCRIPTION	UNFIRED BRICKS MADE FROM BLENDING ACTIVATED GRANITE DUST AND CLAY SOIL	TEMPERATURE(°C)	24
MASS OF MATERIAL		AGE (days) 28	DENSITY OF WATER 1000KG/m³

Clay % and GD %	Trial mix	label	Air dry (g)	SSD (g)	Weight in water (g)	Bulk density (kg/m³)	Water absorption (%)	Average water absorption (%)
100 and 0	Control	CS1	3550	3950	1621	1524	19.78	19.99
		CS2	3558	3958	1631	1529	20.19	
44 and 56	1	A1	3658	3958	1635	1575	17.68	17.54
		A2	3660	3960	1638	1576	17.40	
45 and 55	2	B1	3695	3995	1645	1572	16.57	16.73
		B2	3683	3983	1634	1568	16.89	
46 and 54	3	C1	3690	3810	1638	1699	16.41	16.62
		C2	3717	3817	1635	1703	16.83	
47 and 53	4	D1	3725	3825	1629	1696	16.01	16.00
		D2	3735	3835	1641	1702	15.99	
48 and 52	5	E1	3728	3828	1625	1692	15.74	15.78
		E2	3721	3821	1623	1693	15.82	
49 and 51	6	F1	3794	3894	1630	1676	14.75	14.81
		F2	3785	3885	1649	1693	14.87	
50 and 50	7	G1	3790	3890	1720	1747	14.37	14.46
		G2	3785	3885	1723	1751	14.55	
51 and 49	8	H1	3810	3810	1715	1819	13.44	13.75
		H2	3873	3873	1732	1809	14.06	
52 and 48	9	L1	3825	3852	1705	1782	14.87	14.62
		L2	3830	3850	1700	1781	14.37	
53 and 47	10	J1	3814	3854	1713	1781	14.98	14.97
		J2	3837	3857	1711	1788	14.96	

STIRLING CIVIL ENGINEERING LTD
P.O. BOX 96, KAMPALA (U)

MATERIAL ENGINEER

STUDENTS

MWESIGE JOTHAM KAKANDE HANNINGTON

INSTITUTION	STUDENTS	LABORATORY
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MWESIGE JOTHAM KAKANDE HANNINGTON	Stirling

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	

		Students
Material engineer		Mwesige Jotham Kakande Hannington

STIRLING CIVIL ENGINEERING LTD
MAR 2025
P.O. BOX 736, KAMPALA (U)

INSTITUTION	STUDENTS	LABORATORY
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MWESIGE JOTHAM KAKANDE HANNINGTON	Stirling

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	

STIRLING CIVIL ENGINEERING LTD P.O. BOX KAMPALA (U) Material engineer		Students Mwesige Jotham Kakande Hannington