THE USE OF A BIO-ENZYME AND PINEAPPLE LEAF FIBER AS A STABILIZER IN CLAY BRICKS

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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

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ABSTRACT

This paper investigated the potential of the bio-enzyme and pineapple leaf fiber combination as stabilizers for the clay bricks to decrease the carbon emission firewood the usual material used in the firing process. We present a study covering the effectiveness of the hybrid bio-enzyme (Terrazyme) mixtures with Pineapple Leaf Fiber (PALF) in clay bricks as a detailed description. The results of the field tests performed in Siron clay bricks provided evidence that the use of the new material not only decreases the environmental impact but also improves the strength and water absorption of the brick itself. Which in turn contributes to the construction of the eco-friendly and sustainable building brick.

DECLARATION

I, Ocholla Collin Mike, declare that this research report titled "Assessing the Use of A Bio-Enzyme and Pineapple Leaf Fiber as a Stabilizer of Clay Bricks" is my original work and has not been submitted for any other degree or qualification. All sources and references have been appropriately acknowledged.

SIGNED.. Date: 16/04/2025...

OCHOLLA COLLIN MIKE

S21B32/128

APPROVAL

I hereby certify that OCHOALLA COLLIN MIKE, registration number S21B32/128, successfully undertook her research project at Uganda Christian University during the period of September 2024 to April 2025. Therefore, the work that he was able to complete under my supervision is accurately recorded in this report and is ready for submission for assessment purposes to the department of engineering and environment at Uganda Christian University.

Signed: …………………………………………… Date: …………………………………………….

Eng. Dr. MORRIS OLENG

(Academic Supervisor)

DEDICATION

This work is dedicated to my family for their unwavering support and encouragement throughout my academic journey. It is also dedicated to my Project supervisor, Eng. Dr. Morris Oleng for uniquely inspiring me. I dedicate this research to the countless individuals and communities affected by environmental degradation, with the hope that this research contributes to sustainable practices in construction.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my supervisor, Eng. Dr. Morris Oleng, for his invaluable guidance and support throughout this research project. I also thank my colleagues at Uganda Christian University for their collaboration and encouragement. Special thanks to the local communities in Siron for their participation in this study and to the Ministry of Water and Environment for their insights into traditional brick production practices. Finally, I acknowledge the funding and resources provided by my parents that made this research possible.

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LIST OF ACRONYMS AND ABBREVIATIONS

- CBR: California Bearing Ratio
- CSH: Calcium Silicate Hydrate
- PALF: Pineapple Leaf Fiber
- UCU: Uganda Christian University

CHAPTER ONE

1.1 INTRODUCTION

The construction sector is an economic stimulant but is no less a source of ecological degradation. The extensive application of firewood in Ugandan bricks is directly responsible for carbon accumulation and deforestation. As demands for green building materials rise, innovative ways to stabilizing bricks have to do to lessen the effects on the environment by regular bricks.

Clay bricks, in Uganda, omnipresent for their strength and insulating ability, can completely be exploited by subjecting them to stabilization treatments to convert them to mechanically reinforced and environment-safe bricks. Studies in recent decades have revealed extensive opportunities for application of bio-enzyme technology in quality improvement of clay bricks. In their natural forms, bio-enzymes, microbially produced catalysts, have revealed opportunities to catalyze reactions to improve bonding quality of clay in combinations with traditional stabilizers such as cement and lime.

In addition, fibers such as natural fibers made of pineapple leaf fibers (PALF) have found attention for their ability to strengthen construction materials. PALF is widely available in Uganda, and its utilization in clay bricks would be a sustainable alternative to the limitations provided by traditional stabilization techniques. This study seeks to explore the synergetic effects of pineapple leaf fiber and bio-enzyme on the stabilization of clay bricks in terms of their mechanical strengths, durability, and eco-sustainability.

1.2 BACKGROUND

Uganda, like most developing nations, is faced with an acute shortage of housing resulting from urbanization and population growth. Clay bricks are among the most widely used construction materials for building in both urban and rural areas because they are readily available and affordable. In regions like Kapchorwa, production of clay bricks is normally on a small scale from locally available clay of high plasticity that requires stabilization to enhance strength and durability. Nevertheless, the conventional technique of clay brick firing using firewood is not just energy-consuming but also causing serious environmental concerns. The practice is leading to deforestation, which is resulting in biodiversity loss, soil erosion, and carbon dioxide emission in the environment. Research indicated that the forest cover in Uganda is diminishing at a rate of 1.8% per year, and the majority of the loss is due to fuelwood harvesting for brick kilns (Bodipo-Memba et al., 2022). High plasticity clays, which occur in districts like Kapchorwa, pose further problems. These soils, which have a high montmorillonite content, swell when wet and shrink when dry, making structures constructed from them without stabilization vulnerable to instability. While fired bricks, by making available better compressive strength, alleviate this challenge, they are high in environmental as well as economic kiln cost. Other types of stabilization, and especially those minimizing the use of firewood, are thus sorely required.

Pineapple leaf fiber (PALF) is an abundant agricultural residue in Uganda, particularly in areas where the cultivation of pineapple is widespread like Kayunga, Luwero and Mukono.

Pineapple leaves are presently disposed of as waste during pruning. Nevertheless, the study reveals that PALF has superior tensile strength and binding qualities and can be utilized as reinforcement material in building construction (Razman et al., 2024). By integrating bio-enzyme stabilization techniques with PALF, the present research seeks to investigate an eco-friendly alternative that not only mitigates the issues of plasticity in clay soil but also minimizes environmental degradation linked to conventional brick-making processes.

1.3 PROBLEM STATEMENT

The traditional clay brick production in Uganda relies heavily on firewood, and as such, it results in tremendous deforestation and greenhouse emissions. Firewood fuels over 70% of the energy used in the brick kiln and results in the burning of approximately 92,000 hectares of forest cover annually (Bodipo-Memba et al., 2022). The process is unsustainable and poses a risk to Uganda's natural resources and environmental well-being.

In eastern Uganda, Budadiri, Chelel, Mutufu, and Siron are also affected by expansive smectite clays (Wasajja-Navoyojo et al., 2016; Mukasa-Tebandeke et al., 2015). The clays are highly acidic (0.1-1.85 mol/g) relative to kaolinite clays from central Uganda (Mukasa-Tebandeke et al., 2014). The characteristics, such as enormous chemically active surface areas, influence water absorption and liquid flow behavior (Odom, 1984).

Cement and lime are being widely utilized as stabilizers but are energy-intensive, thus causing greenhouse gas emissions. Environmentally friendly alternatives are urgently needed. Bio-enzymes, i.e., Terrazyme, have the potential to enhance compressive strength and reduce permeability via stable clay aggregates formation (Saini & Vaishnava, 2015). This study suggests mixing bio-enzymes with pineapple leaf fibers for the development of a hybrid stabilization method that reduces the environmental impact of brick manufacturing.

1.4 MAIN OBJECTIVE OF THE STUDY

To assess the use of a bio-enzyme and pineapple leaf fibers as a stabilizer in clay bricks.

1.5 SPECIFIC OBJECTIVES

1. To determine the soil properties of the clay brick.
2. To determine the physical properties of pineapple leaf fibers.
3. To evaluate the engineering properties of stabilized clay bricks and identify the optimal ratio for the mix.

1.6 RESEARCH QUESTIONS

1. What are the soil properties of the clay brick?
2. What are the physical properties of pineapple leaf fibers?
3. What are the engineering properties of a bio-enzyme and pineapple leaf fiber-stabilized clay bricks and the optimal ratio for the mix?

1.7 JUSTIFICATION

In Siron Village, located in Kirwoko Parish, Kaptanya Subcounty, Kapchorwa District, clay soils primarily consist of Montmorillonite, which has a high cation exchange capacity. This leads to significant swelling as the clay absorbs large amounts of water, increasing its volume.

Bio-enzymes like Terrazyme, an organic and non-toxic formulation derived from the fermentation of fruit and vegetable waste, enhance soil engineering properties. Terrazyme catalyzes reactions between clay particles and organic cations, reducing water absorption and increasing compaction (Shah, 2017; Suresh, 2017). Studies indicate improvements in the California Bearing Ratio (CBR) values of treated soil, with optimal results typically at 0.5 ml per 100 ml of water (Suresh, 2017; Panchal, 2017). This treatment enhances soil strength and can reduce pavement thickness, potentially saving up to 30% in road construction costs (Suresh, 2017).

Pineapple leaf fibers (PALF) also show promise as reinforcement in clay and earth bricks, demonstrating tensile strength ranging from 16.71 MPa to 76.47 MPa, with optimal fiber loading (Kasim et al., 2015; Odusote & Kumar, 2016; Susilowati & Sumardiyanto, 2018).

1.8 SCOPE

This research will focus on the clay found in Siron Village, in Kirwoko Parish, Kaptanya Subcounty, Kapchorwa District, Uganda. It will focus on assessing the physical properties of the pineapple leaf fibers, determining their optimal mix for brick stabilization, and evaluating the resulting bricks' engineering properties. The study will involve laboratory testing of bricks stabilized with varying ratios of bio-enzyme and pineapple leaf fiber.

CHAPTER TWO: LITERATURE REVIEW

2.1 CLAY SOILS

Clay soils comprise fine grains composed of clay minerals whose grain is below 2 micrometers. The soils exhibit good plasticity, cation exchange ability (CEC), and holding of water and thus their application is vital in agricultural, civil engineering, and in environment application in Mukono and in Ugandans' eastern regions.

Clay soils have three classes, such as illite, smectite, and kaolinite. Smectite soils have good swelling and good cation-exchanging property, but good for agricultural moisture and bad for building, in case of ground instability. The illite soils have average shrink-shrink and in building, while for low plasticity and strength, kaolinite is valued and good for bricks and for ceramic industry (Belghazdis & Hachem, 2022; Mukasa-Tebandeke et al., 2022).

2.2 PROPERTIES OF SMECITE

Smectite clays have good cation-exchanging capacities, and such capacities are desirable for agricultural application in water scarcity soils (Keren, 2021). Such capacities are desirable for agricultural application in water scarcity. The plasticity is, however, challenging to handle in construction. The illite clays, however, have average plasticity and low shrink-swelling, and such is desirable for application in building, for example, in bricks' manufacture. Kaolinite is desirable for strength and stability under high-temperature, something desirable in strong bricks' and tiles' manufacture (Dixon, 2022).

2.3 CLAY BRICKS

Clay bricks are materials for construction made through molding clay and subjecting them to kilning. In Uganda, their standard measurement is 200mm in length, 100mm in breadth, and 75mm in thickness. The bricks have various applications, including load walls and foundations. The locally produced clay bricks have been used for housing and building on a large scale, and offered an inexpensive and renewable source, in most rural societies where there is adequate clay (Ifurueze et al., 2018).

2.4 STABILIZATION

Stabilization refers to any treatment to improve physical quality of building materials, for instance, soils like clay, to make them resistant and to ensure them to function properly. Stabilization is made up of addition of stabilizers like cement, cement, or bio-enzymes, to which stabilizers have to undergo chemical reaction to soils or materials, to limit their plasticity, to strengthen them, and to protect them against deformation under impact of such natural components such as water and shrinkage.

2.4.1 Chemical Stabilization

Chemical stabilization is made possible through stabilizers such as cement and lime in clay soils to improve their engineering behavior. Stabilizers cement and cement in Uganda have been largely employed. Stabilizer's calcium ions bind to clay minerals to form cementitious compounds, thus increased compressive strength and durability in clay bricks (Riza et al., 2011). Fly ash, combustion residue of coal, is also discovered to be used in stabilizing in various regions, posing an available low-impact solution.

2.4.2 Mechanical Stabilization

Mechanical stabilization compresses the mixture of clay to compact void space and to ensure optimal density. The process strengthens and makes bricks moisture and natural effects resistant. Mechanism is oftentimes employed in Ugandan commercial bricks to ensure standard shapes and dimensions (Firoozi et al., 2017).

2.5 BIO-ENZYMES

Bio-enzymes are natural, organic compounds produced by fermenting plant materials including fruit, vegetable, or cane. In their role as stabilizers, bio-enzymes in stabilizing soils modify physical and chemical states of soils, stabilizing, compacting, and strengthening them to sustain load. As an organic, green cement or lime stabilizers' substitute, bio-enzymes have low carbon footprints and low ecological impact (Sathish et al., 2021).

2.6 Terrazyme as one of the bio enzymes for stabilization

Terrazyme is a commonly used organic liquid enzyme in soil stabilization and soil improvement, made of different vegetable and fruit extracts. Terrazyme positively changes the California Bearing Ratio (CBR) and enhances soil strength while decreasing the Optimum Moisture Content (OMC) and plasticity index (Ikeagwuani, & Nwonu, 2019).

As the water is removed from the soil, the soil particles (mostly clay) have a greater capacity to exchange cations, resulting in increased friction (Agarwal & Kaur, 2018). The Terrazyme coats the clay particles to make them moisture resistant, which ultimately results in a higher long-term stabilizing effect and biodegradability (Jain & Sharma, 2020).

Terrazyme is a dark brown liquid that dissolves in water and has a sweet molasses smell. It is not an eye irritant, and personal protective equipment (i.e. masks and gloves) is not required (Kumar et al., 2021).

Terrazyme must be dosed correctly; under-dosing will have ineffective stabilization, and over-dosing is an unwanted expense without added benefit (Onah et al., 2022). Terrazyme can be dosed appropriately by performing a California Bearing Ratio (CBR) test with soil samples mixed with varying concentrations of Terrazyme to conclude the optimal dosage for stabilization (Ikeagwuani & Nwonu 2019).

Properties of Terrazyme

Table 1 Terrazyme Properties (Navale et al., n.d.)

Property	Value
Boiling Point	Same as water
Solubility in water	Same as water
PH value	3.50
Appearance/ odor	Dark Brown, Non-Obnoxious
Total Dissolved Solids	19.7ppm
Cation Exchange Capacity	3.87
Hazardous Content	None
Melting Point	Liquid
Reactivity Data	Stable
Materials to Avoid	Caustics and Strong Bases.
Specific Gravity	1.05

2.6.1 Mechanism of bio-enzyme stabilization

Bio-enzymes can have a positive impact on the stability of soil through the alteration in soil grain arrangements. In soils with a high clay content, the enzymes can assist in re-aggregation of clay particles from de-aggregation of organic matter, allowing certain chemical reactions to occur that facilitate the decomposition of water-clay bonds

(Ikeagwuani & Nwonu, 2019). The outcome of these actions reduces the swelling-shrinkage behavior of expansive clays and enhances solidification of the soil (Agarwal & Kaur, 2018). The stabilization process includes: Cation exchange reducing clays plasticity through the replacement of the absorbable water molecule with stabilizing ions (Jain & Sharma, 2020).

2.6.2 Promote cation exchange

Bio-enzymes facilitate cation replacement between clay minerals in such a manner in which calcium and magnesium ions replace sodium ions in clay structure. The cation replacement lowers electrostatic repellency between clay materials, and thus, forms denser and stable structure in soils (Narain et al., 2020).

2.6.3 Reduce plasticity

Bio-enzymes significantly constrain plasticity index of the soil, and swelling and water-absorbing ability is compromised. The consequence is to render the soil impermeable to water deterioration and, therefore, wet durability is enhanced (Sathish et al., 2021).

2.7 Natural fibers (Pineapple Leaf Fiber)

Pineapple leaf fibers consist of plant leaves Ananas comosus. The plant is renewable resource and green in accordance to their degradable and renewable property and their available by-product in agricultural industry (Behera et al., 2019). The pine leaf fibers have good extension strength resistance and good strength in building materials, in composites and earth stabilizers.

CHAPTER THREE: METHODOLOGY

3.1 To determine the soil properties of the clay bric

3.1.1 Particle Size Distribution

3.1.1.1 Sieve Analysis

This method evaluated soils with particle sizes ranging from gravel to fine sand. The detailed procedure was as follows.

***Materials required*.**

- A set of sieves with appropriate aperture sizes, typically ranging from 63 mm to 63 µm, depending on the soil sample.
- Mechanical sieve shaker to facilitate consistent sieving.
- Balance readable to 0.01 g for precise measurements.
- Drying oven capable of maintaining temperatures between 105°C and 110°C.
- Metal trays for handling soil samples.
- Sieve brushes for cleaning sieves.
- Sieve analysis worksheet for recording data.

Sample Preparation. The soil sample was Placed in a dried to remove moisture. After drying, it was weighed accurately, m_0.

The sieves were arranged in descending order of aperture size, from largest to smallest, ensuring each sieve was clean and undamaged. And place the dried soil sample onto the top sieve of 63mm.

Secured the sieve stack in the mechanical sieve shaker and operated it for a standard duration, typically 10 to 15 minutes, to ensure thorough separation of particle sizes.

After sieving, carefully removed each sieve, starting from the top, and weighed the soil retained on each sieve separately.

Noted the mass of soil retained on each sieve and calculated the percentage retained relative to the total sample mass.

Determined the cumulative percentage passing each sieve size by subtracting the cumulative percentage retained from 100%.

Plotted the cumulative percentage passing against the corresponding sieve sizes on semi-logarithmic graph paper to produce the particle size distribution curve, which aids in soil classification and assessment.

3.1.2 Atterberg Limits Test (Plastic Limit, Liquid Limit, and Plasticity Index)

The Atterberg Limits (Liquid Limit, Plastic Limit, and Plasticity Index) were determined in accordance with British Standard BS 1377-2:1990. These tests classify fine-grained soils based on their consistency and plasticity. ‘

Liquid Limit (LL) – Cone Penetrometer Method (BS 1377-2:1990, Clause 4.3)

This method determined the moisture content at which a soil transitions from a liquid to a plastic state.

Materials Required:

- Cone penetrometer (30° cone, 80g ± 0.5g total mass).

- Penetration measurement device.
- Mixing tools (spatula, glass plate).
- 425 μm sieve.
- Moisture content containers.
- Oven and balance (readable to 0.01 g).
- Distilled water.

Procedure

The soil sample was air-dried and sieved through a 425 μm sieve.

The sieved soil was mixed with distilled water to form a smooth, homogeneous paste.

The soil paste was placed in the penetrometer cup, and the surface was leveled.

The cone was lowered until it just touched the soil surface, and it was then released for 5 seconds.

The penetration depth of the cone into the soil was measured.

The moisture content of the soil was adjusted, and the process was repeated to obtain at least four penetration readings bracketing 20 mm.

The penetration depth (mm) was plotted against the moisture content (%) on a graph.

The Liquid Limit (LL) was the moisture content corresponding to 20 mm penetration, interpolated from the flow curve.

Plastic Limit (PL) (BS 1377-2:1990, Clause 5.3)

This method determined the moisture content at which a soil transitions from a plastic to a semi-solid state.

Materials Required:

Glass plate.

3 mm rolling rods.

425 μm sieve.

Moisture content containers.

Oven and balance (readable to 0.01 g).

Distilled water.

Procedure

Use approximately 20 g of soil that had passed through a 425 μm sieve.

The soil was mixed with distilled water to form a stiff, plastic paste.

The soil paste was rolled into a 3 mm diameter thread on the glass plate.

If the thread crumbled at 3 mm diameter, the crumbled soil was collected for moisture content determination.

The process was repeated until consistent crumbling occurred at 3 mm diameter.

The moisture content of the crumbled soil was determined.

The results of two trials were averaged to obtain the Plastic Limit (PL).

Plasticity index (PI)

The difference between the liquid limit and the plastic limit was calculated as the plasticity index.

PI = LL – PL (as a percentage)

3.1.3 The X-ray Fluorescence (XRF)

This test was performed to evaluate the chemical composition of clay soil in accordance with ASTM D5381-93 (2021). The clay soil sample was left to air dry, ground to pass through a 75-micron sieve, and weighed (15g), then placed in a plastic sample cup with a support film to establish a flat surface for scanning.

The sample was compacted and area crushed for homogeneous distribution. Standardized reference materials were utilized to calibrate the XRF spectrometer.

The sample was placed into the spectrometer, and an X-ray beam was directed at the surface of the sample while the fluorescence emissions were recorded and analyzed. The XRF assessment provided quantitative data on the percent archaeometric compositions of the significant oxides of SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O and K_2O oxides found in the clay soil. The reported values could then be used to evaluate the soil material for engineering purposes.

The protocols for preparation were strictly followed so accurate results would be obtained. The X-ray fluorescence test will display reliable results for chemical analysis of clay soil. Proper sample preparation, calibration, and positioning provided accurate results in support of decisions such as: soil stabilization, construction material selection, and geotechnical applications.

3.1.4 Free Swell Index (FSI) Test

The free swell test, using the USBR (United States Bureau of Reclamation) method, determined the potential for a soil to swell when exposed to water by measuring the increase in volume of a soil sample after it was immersed in water. This method was developed by Holtz and Gibbs (1956) and was used to assess soil expansivity.

Free swell ratio was defined as the ratio of the equilibrium sediment volume of a 10 g oven-dried soil sample that had passed through a 425 µm sieve and was placed in a 100 ml graduated measuring jar containing distilled water, to that in kerosene, after an equilibration period of a minimum of 24 hours.

This test was used to check volume expansion in water in soils, which was crucial in identifying swelling soils. The swelling property was significant in testing stabilization treatments.

3.1.5 Compressive Strength Test BS EN 772-1:2011

This test was conducted to determine the maximum compressive load that a masonry unit can withstand before failure, crucial for evaluating its structural integrity.

Materials and Apparatus Required:

- Compression testing machine, compliant with BS EN 772-1:2011, capable of applying a controlled compressive load.
- Measuring devices (e.g., calipers, rulers) for accurate measurement of specimen dimensions.
- Appropriate packing materials (e.g., plywood or steel plates) to ensure uniform load distribution.
- Test specimens conforming to the dimensions specified in the standard.

Procedure:

The test specimens were prepared according to the standard, ensuring that the loading surfaces were flat and parallel.

The dimensions of each test specimen were measured and recorded.

The specimen was centered between the platens of the compression testing machine.

If necessary, packing materials were used to ensure uniform load distribution and to prevent premature failure due to uneven surfaces.

The compressive load was applied at a controlled rate, as specified in BS EN 772-1:2011.

The load was continuously applied until the specimen failed, and the maximum load achieved was recorded.

The compressive strength was calculated by dividing the maximum load by the cross-sectional area of the specimen.

The compressive strength and failure mode for each test specimen were recorded.

The average compressive strength of the tested specimens was calculated.

The results were reported in accordance with the standard.

3.1.6 Water Absorption Test BS EN 772-11:2011

This test was performed to determine the amount of water absorbed by a masonry unit, indicating its resistance to moisture and porosity.

Materials and Apparatus Required.

- Water tank or container of sufficient size to fully immerse the masonry units.
- Oven capable of maintaining a constant temperature (typically 105°C ± 5°C).
- Balance, readable to 0.1% of the specimen's mass.
- Clean, dry cloth.
- Distilled or deionized water.

Procedure:

Dried the masonry units in an oven at 105°C ± 5°C until a constant mass was achieved.

Allowed the dried units to cool to room temperature.

Measured and recorded the dry mass (Mdry) of each unit.

Immersed the units completely in water at a specified temperature (typically room temperature).

Soaked the units for a specified period (e.g., 24 hours), as required by the application or standard.

Removed the units from the water and allowed excess water to drain off.

Wiped the surface of each unit with a damp cloth to remove surface water.

Measured and recorded the saturated mass (Msat) of each unit.

Calculated the water absorption (Wa) as a percentage of the dry mass using the formula: Wa = $\frac{(Msat - Mdry)}{Mdry} \times 100$

Recorded the results for each unit and calculated the average water absorption for the sample.

3.2 Determining Physical Properties of Pineapple Leaf Fiber

Production of Pineapple Leaf Fiber (PALF)

The production of pineapples fibres was achieved by plucking green leaves of pineapples, scratching them by blunt knife to expose the fibers.

The fibers are then treated in alkaline solution inform of Wood Ash treatment for suitability for a rural setting.

The fibres are dried in 24-48 hours in aerated atmosphere until dry. The dry fibres, last, keep in closed, moisture proof packages to maintain them in good quality and free moisture, for testing their physical and chemical characters.

Physical Properties Evaluation of PPLA

3.2.1 Tensile Strength Test (ASTM D2256).

This test, performed according to ASTM D2256, measured the following properties:

- Breaking Force (gf)
- Elongation (mm)
- Fiber Strength (RKM - breaking length, g/tex)
- Breaking Work (gf*cm)
- Time to Break (s)

- **Materials and Apparatus Required:**
  - Tenso aster Tester (Tensile Testing Machine / Universal Testing Machine)
  - PPLA fiber samples
  - ASTM D2256 standard document
- **Procedure:**

Prepared fiber samples according to the specifications outlined in ASTM D2256.

Measured and recorded the initial dimensions of each fiber sample.

Securely clamped the fiber sample between the grips of the Tenso Aster Tester.

Applied a tensile load at a controlled rate, as specified in the standard.

Recorded the force and elongation during the test.

Continued applying the load until the fiber broke, recording the breaking force, breaking work, and time to break.

Calculated the tensile strength, elongation, and fiber strength (RKM).

Recorded the results for each fiber sample and calculated the average values.

Reported the results in accordance with ASTM D2256.

3.2.2 Fiber Diameter Measurement.

Tool: Vernier Caliper

To accurately measure an object with a Vernier caliper, first ensured clean jaws and proper zeroing. Then, gently placed the object between the jaws, gripped it securely, and aligned the Vernier scale. Read the whole unit from the main scale and the fractional part from the Vernier scale by identifying the aligned lines. Finally, added these values together to obtain the total measurement.

3.3 *To evaluate the engineering properties of stabilized clay bricks and identify the optimal ratio for the mix.*

3.3.1 Bio-Enzyme ratios

The bio-enzyme Terrazyme used in this study was sourced from Nature Plus, Inc., a recognized supplier of soil stabilization products, and obtained through a local distributor Ultra chemis Co. Ltd, plot 45, Mulwana road, Bugolobi industrial area, K'la, opposite Uganda Baati. Terrazyme was mixed with water in varying proportions prior to application, facilitating an enzymatic reaction upon contact with the soil. The specific properties of Terrazyme utilized in this study are detailed in Chapter 2, Table.

The bio-enzyme was mixed in different ratios of 0 ml/m³, 50 ml/m³, 100 ml/m³, and 150 ml/m³ of soil, with the Terrazyme first diluted in water before being incorporated into the clay-compost mixture.

The bio-enzyme was mixed in different ratios of 0 ml/m³, 50 ml/m³, 100 ml/m³, and 150 ml/m³ of soil, but was first mixed in water.

3.3.2 Pineapple Leaf Fiber (PALF) Proportions

PALF ratio used is 0%, 1%, 2% and 3% by weight of soil. and their impact on strength and shrink resistance in materials made of clay-compost.

Mix Proportions

Various mixtures proportions have to be tried, using bio-enzyme and PALF in ranges

	Pineapple Leaf Fiber (%)			
		0%	**1%**	**2%**
Bio-Enzyme (ml/m³)	0 ml/m³	0 ml/m³, 0%	0 ml/m³, 1%	0 ml/m³, 2%
	50 ml/m³	50 ml/m³, 0%	50 ml/m³, 1%	50 ml/m³, 2%
	100 ml/m³	100 ml/m³, 0%	100 ml/m³, 1%	100 ml/m³, 2%
	150 ml/m³	150 ml/m³, 0%	150 ml/m³, 1%	150 ml/m³, 2%

Each combination was mixed in their totality in earth to yield an equivalent quantity of both bio-enzyme and PALF.

Considering the final test being the strength test and water absorption test, all done in triplicates, the total number of bricks made was 96 clay bricks.

3.3.3 1. Compressive Strength Standard Test.

Standard: BS EN 772-1:2011 - Test for masonry units. Compressive strength.

This was to test stabilized clay load-baring strength. The greater compressive strength is evidence for greater stabilization and hence strength.

3.3.4 2. Water Absorption Test Standard.

Standard: BS EN 772-11:2011 - Test for masonry components. Part 11: Water absorption.

This test was to verify volume of water absorbed by the brick in 24 hours under soaking in water. Water absorption rate is to be determined by before and after soaking in water. Water absorption values, if low, will illustrate good moisture resistance and durability.

CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter discusses and examines the findings from several test results of the materials tested and compared to the existing requirements. These tests included those carried out on the existing bricks and soils and the stabilized bricks. The tests include; strength test, water absorption test, the Atterberg limits test and the free swell index test.

4.1 Objective one: Determining the soil properties of the clay brick.

The soils were analyzed at the Stirling Laboratory in Malaba, Mukono, after being

collected from Siron village, Kapchorwa District. The soil was greyish in color and several tests were carried out on it and these include; particle size distribution, Atterberg tests, free swell Index. The strength and water absorption of the site bricks were also tested and these were carried out on both the fired and unfired bricks.

4.1.1 Particle Size Distribution

1. ***Sieve analysis***

Sieve Size (mm)	Passing (%)
4.750	99.0
2.360	97.0
1.180	94.0
0.425	90.0
0.075	80.0

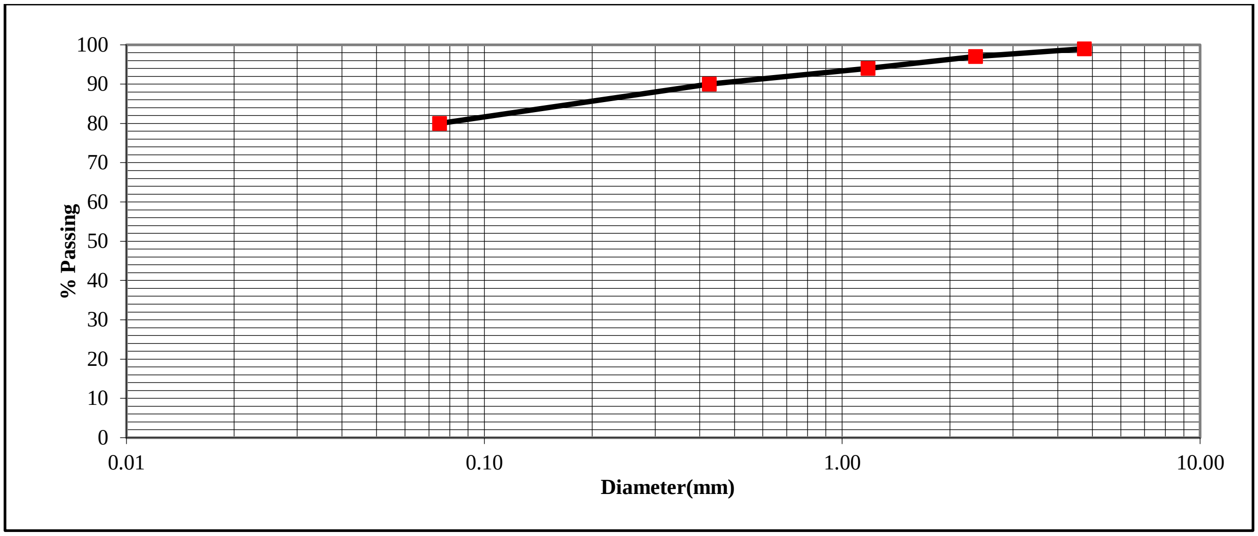


Figure 1 Particle size Distribution

The results indicated that the coarser fractions (sand-sized particles) are minimal, with only 1% retained on the 4.75 mm sieve while, a large portion (80%) of the sample is finer than 0.075 mm, which means the sample is mostly fine-grained material and based on BS 1377-2:1990, soils with a high percentage of fine particles are typically clayey silts or clays. This confirms that the soil is predominantly a fine-grained material, likely clayey soil, which aligns with the project's focus on stabilizing clay bricks.

4.1.2 Atterberg Limits test on the clay soil sample

The Atterberg Limits—Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI)—are critical indicators of the engineering behavior of fine-grained soils, particularly their response to moisture changes. The results for the clay soil from Siron Village, Uganda, are as follows:

Liquid Limit (LL): 57.6%

Plastic Limit (PL): 27.6%

Plasticity Index (PI): 30.0%

Liquid Limit (LL)

The LL of 57.6% signifies the soil's high water-holding capacity, characteristic of montmorillonite-rich clays. At this moisture content, the soil transitions from a plastic to a liquid state. Such a high LL suggests that the soil is prone to significant volume expansion when saturated, making it unsuitable for construction without stabilization. Montmorillonite's layered structure and high cation exchange capacity (CEC) exacerbate this behavior, as water molecules infiltrate the mineral layers, causing swelling.

Plastic Limit (PL):

The PL of 27.6% represents the moisture content below which the soil becomes brittle and cracks under stress. While this value is moderate compared to highly organic soils, it underscores the soil's sensitivity to drying. During brick production, maintaining moisture slightly above the PL is essential to ensure workability. However, exceeding this threshold risks deformation, while under-drying leads to brittleness.

Plasticity Index (PI):

The PI (LL − PL = 30.0%) categorizes the soil as highly plastic (PI > 25%). According to the Unified Soil Classification System (USCS), this soil falls under CH (high-plasticity clay). High PI soils exhibit pronounced shrink-swell behavior, expanding when wet and contracting when dry. The PI (30%) aligns with studies on Ugandan montmorillonite clays, which report PI values of 25–35% (Mukasa-Tebandeke et al., 2022).

USCS classification Chart

The Unified Soil Classification System (USCS) classifies soils based on their particle size distribution and plasticity characteristics. Based on the results archieved, the soil sample can be classified as follows:

Major divisions			Group symbol	Group name
Coarse grained soils more than 50% retained on or above No.200 (0.075 mm) sieve	gravel > 50% of coarse fraction retained on No.4 (4.75 mm) sieve	clean gravel <5% smaller than No.200 Sieve	**GW**	well-graded gravel, fine to coarse gravel
			GP	poorly graded gravel
		gravel with >12% fines	**GM**	silty gravel
			GC	clayey gravel
	sand ≥ 50% of coarse fraction passes No.4 (4.75 mm) sieve	clean sand	**SW**	well-graded sand, fine to coarse sand
			SP	poorly graded sand
		sand with >12% fines	**SM**	silty sand
			SC	clayey sand
Fine grained soils 50% or more passing the No.200 (0.075 mm) sieve	silt and clay liquid limit < 50	inorganic	**ML**	silt
			CL	lean clay
		organic	**OL**	organic silt, organic clay
	silt and clay liquid limit ≥ 50	inorganic	**MH**	elastic silt
			CH	fat clay
		organic	**OH**	organic clay, organic silt
Highly organic soils			**PT**	peat

Figure 2 USCS classification Chart (California Department of Transportation (Caltrans))

Grain Size Distribution Analysis:

- 80% of the soil passes through the 0.075 mm sieve, indicating that it is a fine-grained soil.
- According to the USCS, soils with more than 50% passing through the 0.075 mm sieve are classified as **fine-grained soils (silts or clays)**.

Plasticity Analysis:

- **Liquid Limit (LL) = 57.6%**
- **Plasticity Index (PI) = 30.0%**
- According to the USCS classification:
  - If **LL > 50%**, the soil is classified as **high plasticity**.
  - A **PI of 30%** confirms that the soil exhibits high plasticity, meaning it undergoes significant volume changes with moisture variation.

USCS Plasticity Chart provided below in fig 2. along with the test results, we can **visually and logically confirm** the soil classification.

- **LL = 57.6** on the x-axis of the chart.
- **PI = 30.0** on the y-axis.
- Plotted the point **(57.6, 30.0)** on the graph.

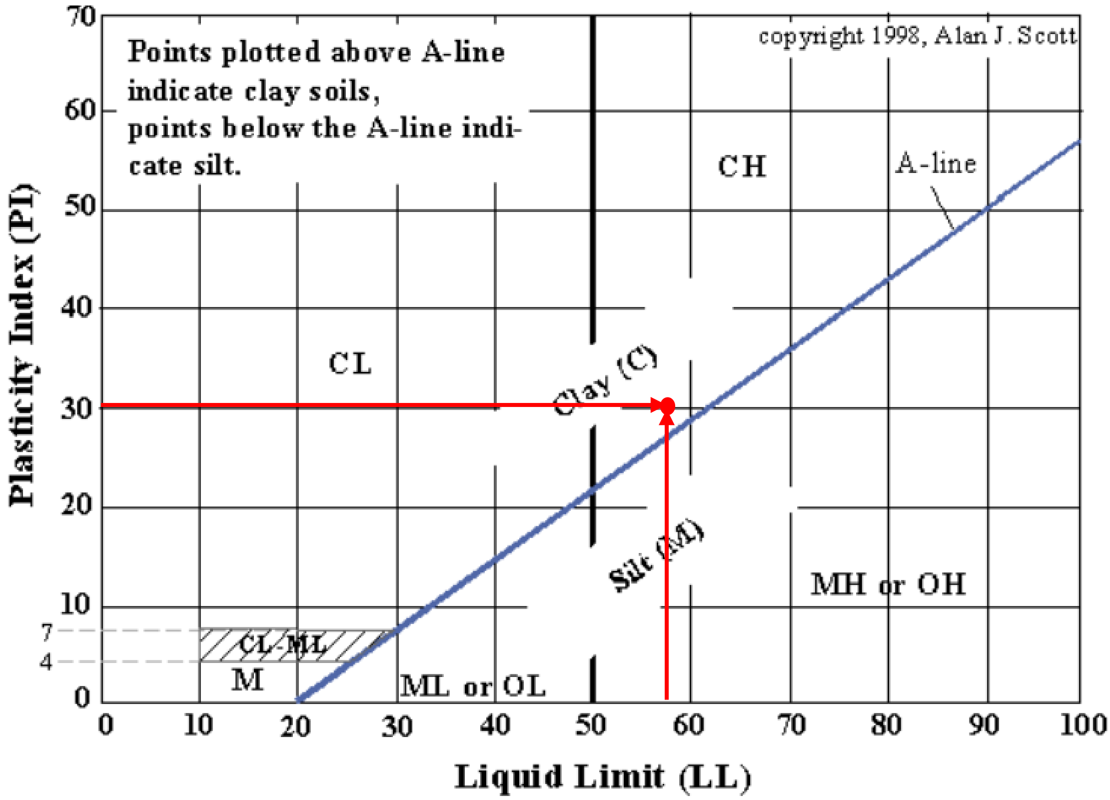


Figure 3 Plasticity Chart for USCS

From the chart:

- The plotted point lies **above the A-line**.
- It is located in the **CH zone**, which stands for **Clay of High Plasticity**

4.1.3 XRF test of the clay soil

The X-Ray Fluorescence (XRF) analysis provides a chemical composition of Siron clay, which is compared with Illite and Montmorillonite clay standards. This comparison helps in classifying the soil type and understanding its behavior in engineering applications.

Table 2 XRF test Results of siron soil.

Oxide (%)	Siron Clay	Illite	Montmorillonite
SiO_2 (Silicon Dioxide)	**48.27**	**50-60**	**55-65**
Al_2O_3 (Aluminum Oxide)	**20.53**	**15-25**	**20-30**
Fe_2O_3 (Ferric Oxide)	**10.18**	**4-8**	**2-5**
CaO (Calcium Oxide)	**7.32**	**0-3**	**1-5**
MgO (Magnesium Oxide)	**4.22**	**1-3**	**3-10**
K_2O (Potassium Oxide)	**3.56**	**3-7**	**0.5-3**
Na_2O (Sodium Oxide)	**2.87**	**0.5-2**	**1-4**
TiO_2 (Titanium Dioxide)	**1.23**	**0.5-1.5**	**0.2-1**
MnO (Manganese Oxide)	**0.85**	**<0.5**	**<0.5**
CuO (Copper Oxide)	**0.29**	**Trace**	**Trace**

Comparison of Siron Clay (XRF Results) to Illite and Montmorillonite Clay Standards

To assess the characteristics of the **clay soil from Siron, Kapchorwa District**, a comparison on its chemical composition was made to the standard compositions of **Illite and Montmorillonite clays**. This helped determine which category it closely aligns with and how it influences the **stabilization and engineering behavior** of the soil.

Key Observations & Comparisons

1. Silica (SiO_2) Content

Siron Clay: 48.27%

Illite Range: 50–60%

Montmorillonite Range: 55–65%

- **Siron clay has slightly lower silica content than Illite and Montmorillonite**, meaning it may have lower resistance to shrinkage and expansion.

2. **Aluminum Oxide (Al_2O_3) Content**

Siron Clay: 20.53%

Illite Range: 15–25%

Montmorillonite Range: 20–30%

- Siron clay matches closely with Montmorillonite in Al_2O_3 content, suggesting it has good plasticity but potential shrink-swell issues.

3. **Iron Oxide (Fe_2O_3) Content**

Siron Clay: 10.18%

Illite Range: 4–8%

Montmorillonite Range: 2–5%

- **Siron clay has much higher Fe_2O_3 than both Illite and Montmorillonite.** This means it will **produce reddish bricks when fired** but may also be **more brittle** than Montmorillonite clays.

4. **Calcium Oxide (CaO) Content**

Siron Clay: **7.32%**

Illite Range: **0-3%**

Montmorillonite Range: **1-5%**

- **Siron clay has significantly higher CaO, closer to Montmorillonite, making it more self-stabilizing** but prone to **lime popping (expansion issues)**.

5. Magnesium Oxide (MgO) Content

Siron Clay: 4.22%

Illite Range: 1–3%

Montmorillonite Range: 3–10%

- Siron clay has MgO within the Montmorillonite range, meaning it has some self-hardening properties but not as much as high-MgO Montmorillonite. And also contributes to the swelling potential of the clay.

6. Potassium Oxide (K_2O) Content

Siron Clay: 3.56%

Illite Range: 3–7%

Montmorillonite Range: 0.5–3%

- **Siron clay is similar to Illite in K_2O content**, meaning it may have **some resistance to chemical weathering and high-temperature durability**.

7. Sodium Oxide (Na_2O) Content

Siron Clay: 2.87%

Illite Range: 0.5–2%

Montmorillonite Range: 1–4%

- **The Na_2O content in Siron clay is greater than that in Montmorillonite, meaning it is responsible for the swelling potential in this clay.**

4.1.4 Free Swell Index (FSI) Test (BS 1377-2:1990)

FSI = 85.41% which was quite high and it occurs due to high presence of sodium ions, Magnesium ions primarily. This means the clay soil swells when wet and shrinks when dry.

How swelling occurs;

- Montmorillonite has weak Van der Waals forces and cation exchange sites (Na^+, and Mg^{2+}) that attract water molecules, leading to interlayer expansion.
- Illite swells moderately because its interlayers contain K^+ ions, which hold the structure but allow slight expansion.

Thus, high FSI values suggest the presence of Montmorillonite, while low values indicate Kaolinite-dominant soil.

Table 3 Standard Classification of Swelling Potential (as per IS 1498-1970 & Literature Studies)

FSI (%)	Swelling Potential	Reference
<50%	Low Swelling	IS 1498-1970, Seed et al. (1962)
50-100%	Moderate to High Swelling	Holtz & Kovacs (1981)
>100%	Very High Swelling	Sridharan & Prakash (2000)

The value of 85.41% is high and could have adverse effects if the caly soil is utilized without a form of stabilization.

4.1.5 The compressive strength test

The compressive strength test evaluates the ability of bricks to withstand axial loads, which is crucial in determining their structural applicability. The results for the Siron clay bricks are compared against the BS EN 772-1:2011 and BS EN 771-1 standards, as shown in the table below:

Table 4 Siron bricks compressive test results.

Brick Type	Tested Siron brick Strength (MPa)	BS Minimum Standard (MPa)	Meets Standard?
Fired Bricks	3.9	≥5 MPa (BS EN 772-1:2011)	No
Unfired Bricks	1.7	≥2 MPa (BS EN 771-1)	No

Fired bricks (3.9 MPa vs. 5 MPa Standard)

The fired bricks from the case study had an average compressive strength of 3.9 MPa, which is considerably lower than the 5MPa compressive strength set as a threshold by BS EN 772-1:2011 for loadbearing walls.

Fired bricks from the case study could be appropriate for a non-load bearing application (e.g., partition walls), but in other applications for load-bearing mortar with a gross over-design will raise the safe load-bearing capacities of these bricks, possibly rendering them suitable with other allowances of safety values.

Fired bricks that do not structurally qualify as load bearing can be acceptable for walls or foundations with reinforcement, but the lack of strength for broader or unlimited use must be established for any particular circumstance.

The lower strength may have multiple sources, such as:

- Clay mineral composition: Higher proportions of smectite or montmorillonite may yield higher shrinkage and cracking when fired too thoroughly.
- Firing conditions: If the kiln temperature to not achieve a high enough temperature (850 to 1100°C for fired bricks), then the dissipation of heat may leave the bricks incompletely sintered with badly weak inter-particle bonding.
- Pore structure: If the clay is not adequately compacted before firing they may have too much porosity leading to lower strength.

Unfired bricks (1.7 MPa versus a 2 MPa standard)

The unfired bricks registered an average compressive strength of 1.7 MPa which is lower than the 2 MPa minimum required by British Standards, BS EN 771-1, for non-fired load-bearing units, meaning that unfired bricks are structurally weak for any load-bearing applications without additional stabilization.

The expected low strength of the unfired bricks is due to:

- Lack of sintering: Unlike fired bricks, unfired bricks are air-dried, which leads to a higher level of porosity and weak particle cohesion.

- Plasticity of clay: The high plasticity index (30%) indicates that the clay has a high shrink-swell potential that is detrimental to strength.
- No stabilizers: Lime, cement or bio-enzymes could help improve the compressive strength of the unfired bricks. The Siron fired bricks (3.9 MPa) and unfired bricks (1.7 MPa) tested are not representative of the minimum for BS EN 772-1:2011 and BS EN 771-1 (non-fired) standards respectively.

Further improvements to firing conditions, stabilization of the clay, and compaction of the bricks are necessary to improve the quality of the material for structural applications.

4.1.6 Water Absorption Test

The Water Absorption Test is an important measure of the durability, porosity and resistance to moisture penetration of a brick. It simply measures the amount of water a brick can absorb when immersed in water for a period of time (normally 24 hours) expressed as a percentage of its dry weight. Water Absorption Test results against BS standards.

Table 5 Water Absorption Test Results vs. BS Standards

Brick Type	Tested Siron Brick Water Absorption (%)	BS Minimum Standard (%)	Meets Standard?
Fired Bricks	7.6	≤15% (BS EN 772-11:2011)	Yes
Unfired Bricks	-14.0 (Mass loss due to disintegration)	≤20% (BS EN 771-1)	No (Structural collapse)

Fired Bricks (7.6) % - Meets BS Standard

The fired bricks' water absorption of 7.6% is below the BS EN 772-11:2011 standard limit of ≤15% therefore, these bricks can be classified as suitable and are sufficiently resistant to water for construction purposes.

The minimal absorption demonstrates a level of sintering took place during the firing process, which leads to:

• Reduced porosity due to fusion of clay particles.

• Stronger interparticle bonding that reduces water absorption. It falls in line with common Ugandan fired bricks, which usually have a water absorption rate of 8–12%.

The Fired Bricks (7.6% water absorption rate), can meet BS EN 772-11:2011 and are considered suitable for structural use, however, from a sustainability perspective, we need to consider alternate methods of stabilization, as the firing process raises environmental concerns:

• A result of firewood use resulting in deforestation in Uganda (Bodipo-Memba et al., 2022).

• Carbon emissions released from the kiln discharge into the environment, thus affecting sustainability.

• Additional methods of stabilization such as bio-enzyme stabilization or improvements to the industrial kilns could produce a more environmentally friendly policy.

Unfired Bricks (-14.0%) - Fails BS Standard

The negative absorption value (-14.0%) reflects the mass lost from the clay brick due to structural collapse as opposed to absorption. The brick suffered mass loss due to:

- Montmorillonite-rich clay swells upwards of 85% in volume due to absorption of water into the interlayer spaces, which caused disintegration of the compact clay brick after 24 hours.
- High plasticity index (PI = 30%), indicating high sensitivity to moisture.

Unfired Bricks (-14.0%) failed BS EN 771-1 entirely due to swelling and disintegration. They will require further stabilization with bio-enzymes, lime or cement before they can be used practically.

4.2 *Objective two: To determine the physical properties of pineapple leaf fibers.*

The Pineapple Leaf Fiber (PALF) Tensile Properties Test evaluated the mechanical behavior of the fiber subject to tensile stress. This test examined key properties of the fiber, including breaking force, elongation, resistance per kilometer (RKM), breaking work, and breaking time, which will determine suitability of the fiber for reinforcement materials, composites, and textile uses.

Table 6 PALF Properties test

Tests	**Breaking force(gf)**	**Elongation(mm)**	**RKM(g/tex)**	**Breaking work(gf*cm)**	**Time to break(s)**
average	169.40	6.00	7.95	52.86	0.72

Tensile Testing

The test was conducted utilizing a Tensotester, a precise tensile instrument utilized to measure tensile strength and elongation of fibers. The system measures important parameters during the test, which include maximum force at break (breaking force), elongation at break, and energy absorbed (breaking work).

Table 7 PALF Tensile Properties vs. Natural Fiber Standards

Property	**Tested PALF Value**	**Typical Range for Natural Fibers**	**Meets Standard?**
Breaking Force (gf)	169.40	150 – 500	Yes

Elongation (mm)	6.00	3 – 7	Yes
RKM (g/tex)	7.95	5.0 – 10.0	Yes
Breaking Work (gf·cm)	52.86	Varies by fiber type	Moderate
Time to Break (s)	0.72	N/A	-

(Literature reference: Gassan and Bledzki, 1999; Ramakrishna and Seneviratne, 2002; Nouri et al., 2016.)

Breaking Force (169.40 gf)

The breaking force of 169.40 gf is of the expected capacity for natural fibers like sisal and jute (150–500 gf) and indicates a moderate tensile strength for PALF.

From the result, it can be established that PALF can cope with reasonable tensile loads and is recommended for low to moderate structural applications such as brick stabilization: PALF can be used to reinforce stabilized bricks to improve their mechanical strength.

In addition to the breaking force, the cellulose microfibril arrangement of fibers, which affects the yarns capacity to sustain loads, is the reason for this breaking force. PALF will not have capacity for high stress applications, especially when considering synthetic fibers like polyester that have breaking forces of 600–900 gf.

Elongation (6.00 mm) – Moderate Flexibility

The elongation of 6.00 mm for PALF is relatively in the same range as other natural fibers such as kenaf and sisal, which typically range from 3–7 mm, confirming its moderate elongation properties, which suggest:

- The PALF has some level of softness and flexibility, which may make it suitable for composites that would benefit from slight deformation when placed under load.
- The stiffness of the PALF fiber is considered relatively high and likely brittle, which means, when placed under extreme tension, it could fail suddenly. Comparing previous research and Uganda fiber-based applications:
- Linked to, composite materials from banana fiber (with an elongation of ~5%) have been utilized in Uganda as woven mats and reinforcement for other materials.
- The elongation properties of PALF could suggest the original use in soil stabilization, where controlled elongation under applied load may mitigate cracking.

Fiber Strength (RKM = 7.95 g/tex)

Measuring the RKM of PALF at 7.95 g/tex is a good strength to weight ratio that is comparable to sisal at a range of 5.0–10.0 g/tex, which suggests the PALF:

- Could be used as a reinforcing agent in a low load structural composite.

- Provides light reinforcement of material with the loaded benefit of weight reduction while having improved mechanical stability.

Overall, PALF exhibits moderate strength under tension, reasonable elongation properties, and a fairly good strength to weight ratio. All attributes make it suitable for composite materials, soil stabilization, and low weight load reinforcement applications.

Tensile Strength

Breaking Force (F) = 169.40 gf

- 1 gf = 0.00981 N
- F = 169.40 × 0.00981 = 1.661 N
- Fiber Diameter (d) = 70 μm = 0.07 mm
- Cross-sectional Area (A) = $\pi(d/2)^2$

Breaking Force 169.40 gf

$\sigma = \frac{F}{A}$

$1\ gf = 0.00981\ N$

$F = 169.40 \times 0.00981 = \mathbf{1.661 N}$

$$A = \pi \left(\frac{d}{2}\right)^2$$

$A \approx 0.0039 mm^2$

$\sigma = \frac{F}{A} = \frac{1.661}{0.0039} \approx \mathbf{426\ MPa}$

The tensile strength of PALF (426 MPa) highlights its considerable mechanical potential for sustainable engineering applications. Strength equal to sisal and greater than jute and coir implies suitability for applications such as fiber-reinforced composites, sustainable construction, or biodegradable textiles. When processed and treated appropriately, PALF can be considered a strong and sustainable alternative to synthetic fibers for 21st-century engineering applications.

4.3 Objective Three: Evaluating the engineering properties of stabilized clay bricks and identify the optimal ratio for the mix.

Test for Compressive Strength

The compressive strength test followed BS EN 772-1:2011 standards using a universal testing machine (UTM). The bricks were crushed under axial load, and the peak load was determined.

The stabilized clay bricks engineering properties were evaluated to assess strength and water durability. The primary aim was to investigate the ideal bio-enzyme and pineapple leaf fiber mix to attain strength while balancing mechanical performance and environmental sustainability.

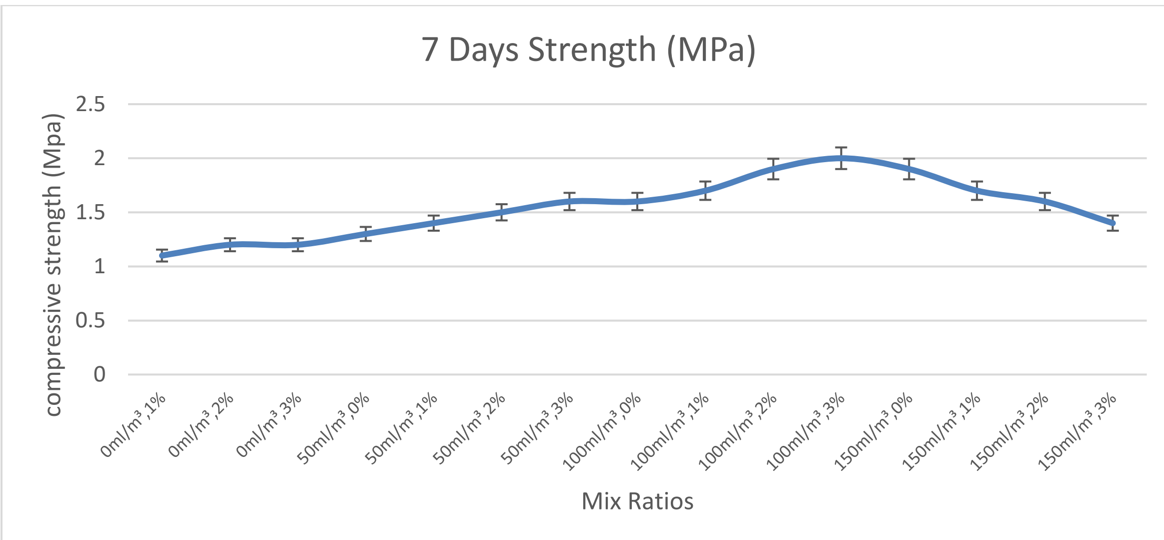


Figure 4 Compressive Strength at 7 days

The bricks were firstly tested at 7 days and the compressive strength gradually increased from 1.1 – 1.2 Mpa at 0ml/m^3 of bio enzyme and 1%,2% and 3% of fiber which meant that this achieved compressive strength was greatly influenced by the fibers. And with increase in the enzyme concentration 50 ml/m^3 and corresponding fiber content, there's an increase in the strength of the brick from 1.3 – 1.6Mpa.

The peak strength is attained at 100 ml/m^3 bio enzyme concentration and 3% fiber content because almost all the bio enzyme organic cations have neutralized the clay allowing for full clay bonding. Hence achieving a compressive strength of 2.0Mpa

At concentrations of 150 ml/m^3, the strength of the brick begins to decrease from 2.0Mpa to 1.4Mpa. This could be attributed to the fact that the bio enzyme is in excess and this makes the unbounded organic cation change the clay particle charges causing sort of repulsion between the clay particles.

Therefore, this highest value attain at 7 days was a 2.0Mpa at the bio enzyme concentration of 100ml/m^3 and 3% fiber, meaning the fiber play a key role in enhancing bonding. However, this value can be higher since the there is high moisture between the clay particles leading to sliding between these particles hence lower strength.

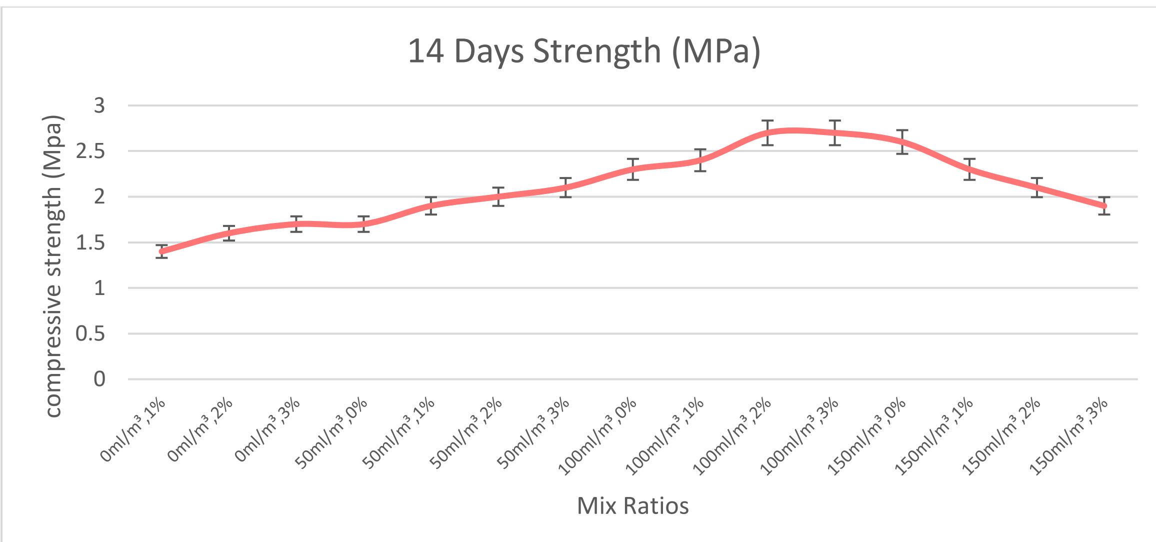


Figure 5 Compressive Strength at 14 days

At 14 days the clay particles have lower moister between them and hence bonding is enhanced resulting to higher attained compressive strengths of up to 2.7Mpa at a bio enzyme concentration of 100ml/m^3 and 2-3% of the fiber. This shows that there is less moisture leading to increased friction between the clay particles hence greater bonding.

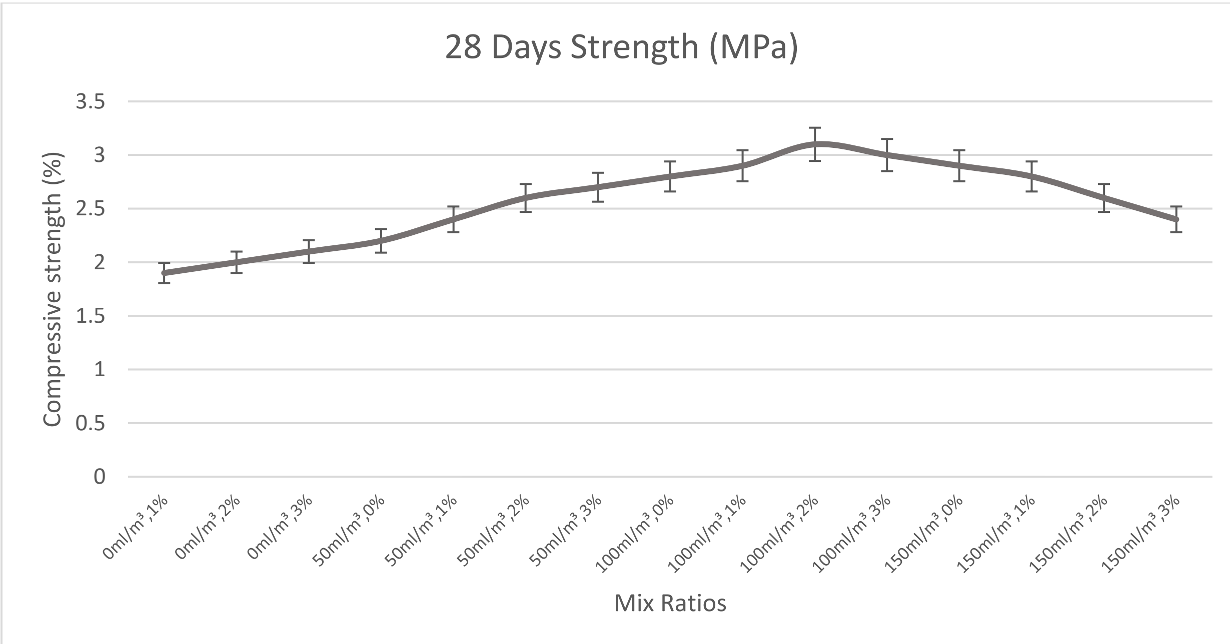


Figure 6 Compressive Strength at 28 days

At 28 days the brick is fully dry and hence there's not limitation of strength due to availability of moisture hence attaining at strength of 3.1Mpa at 100ml/m^3 of bio enzyme and 2% of fiber. This could be attributed to the fact that the Bio enzyme organic cations have fully been exchanged in the clay to neutralize it to allow to full bonding of the clay particles.

It is also observed that beyond this concentration i.e. 150ml/m^3, the strength decreases gradually to 2.4Mpa because the excess organic cations in the clay cause repulsion between the clay particles leading to weaker bonding.

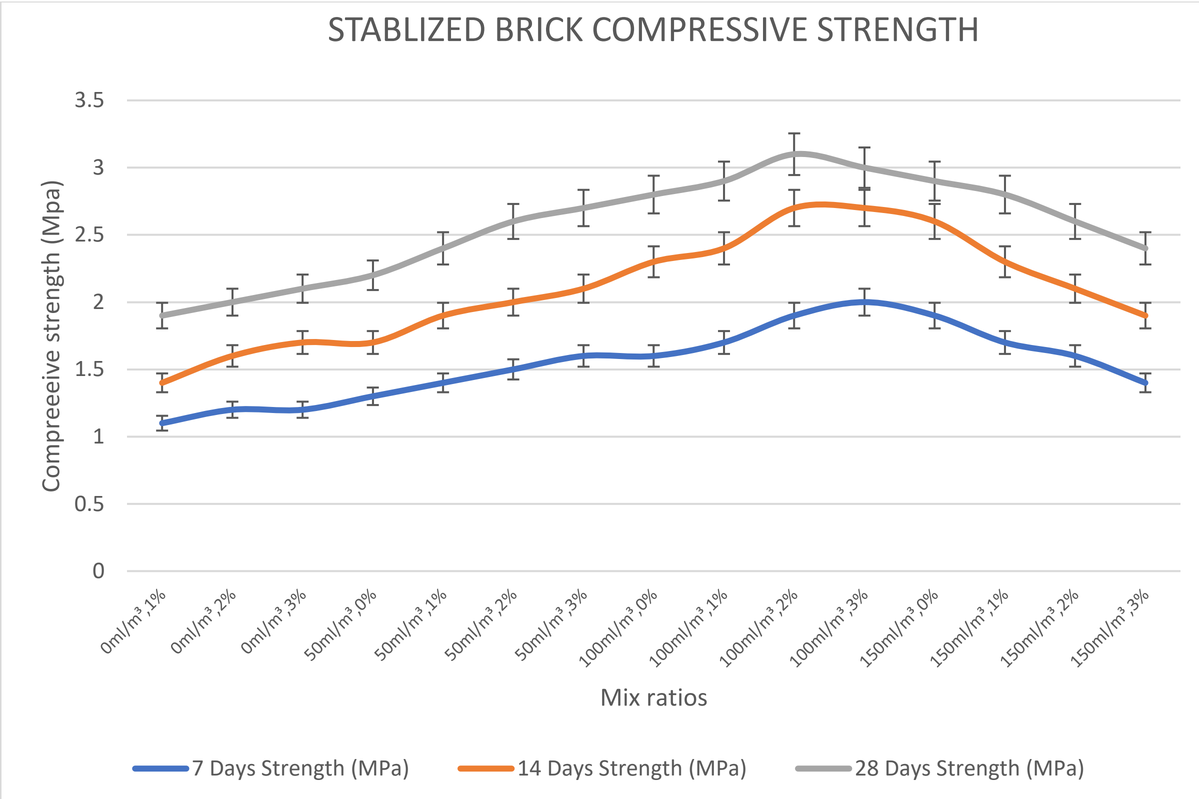


Figure 7 Compressive Strength during curing

The compressive strength of stabilized bricks was assessed at 7, 14, and 28 days, from Figure 3 all compressive strength had a trend of increasing compressive strength until optimal bio-enzyme dosage was reached, then a decrease. The compressive strength after 28 days ranged between a minimum of 1.9 MPa to a maximum of 3.1 MPa, contingent upon the mix ratio.

- Strength continues to increase for all curing ages (7, 14, and 28 days) as bio-enzyme dosage increases from 0 ml/l to 100 ml/l, with additional PALF.
- Bio-enzyme increases bonding between clay particles through electrochemical structure modification, increasing cohesion among the particles.

Pineapple leaf fiber (PALF) acts as a reinforcement improving micro-crack resistance.

Peak Strength at 100 ml/l Bio-Enzyme & 2% PALF

At 28 days, compressive strength of 3.1 MPa is achieved at 100 ml/l bio-enzyme and mixed with 2% PALF.

At optimal levels of bio-enzyme the charge could be balanced which allowed compacting without sacrificing bond formation.

PALF contributes towards structural integrity without sacrificing workability. Strength

Reduction Beyond 100 ml/l Bio-Enzyme

Strength begins to degrade when the bio-enzyme exceeds 100 ml/l. This is because excess enzymes create a charge which leads to electrostatic repulsion between clay particles.

- Delayed strength gain- The excess bio enzyme affects hydration kinetics inhibiting the binding process.

Table 8 Comparison with Compressive Strength Standards

Standard	Required Compressive Strength (MPa)
Uganda National Bureau of Standards (UNBS)	2.8 MPa – 3.5 MPa
Indian Standard IS 3495	3.5 MPa (for load-bearing bricks)
ASTM C62	2.75 MPa (for medium-duty bricks)

Findings:

- The most effective stabilized bricks (100 ml/l, 2% of PALF) attained a 3.2 MPa level which is acceptable according to the UNBS standard for structural purposes.
- Bricks with an excess of bio-enzyme (>100 ml/l) had a value of less than 2.5 which is unacceptable for high-strength applications.

4.3.1 4.3.1 Water Absorption Test

Testing the water absorption is a standard test that is conducted on stabilized bricks to assess their durability and performance in water. This was previously tested during the unfired clay brick testing, as it was disclosed that the brick ratio disintegrated, giving reading of -14%. It is reasonable to suppose that the same ratio of disintegration would be reflected in the stabilization bricks.

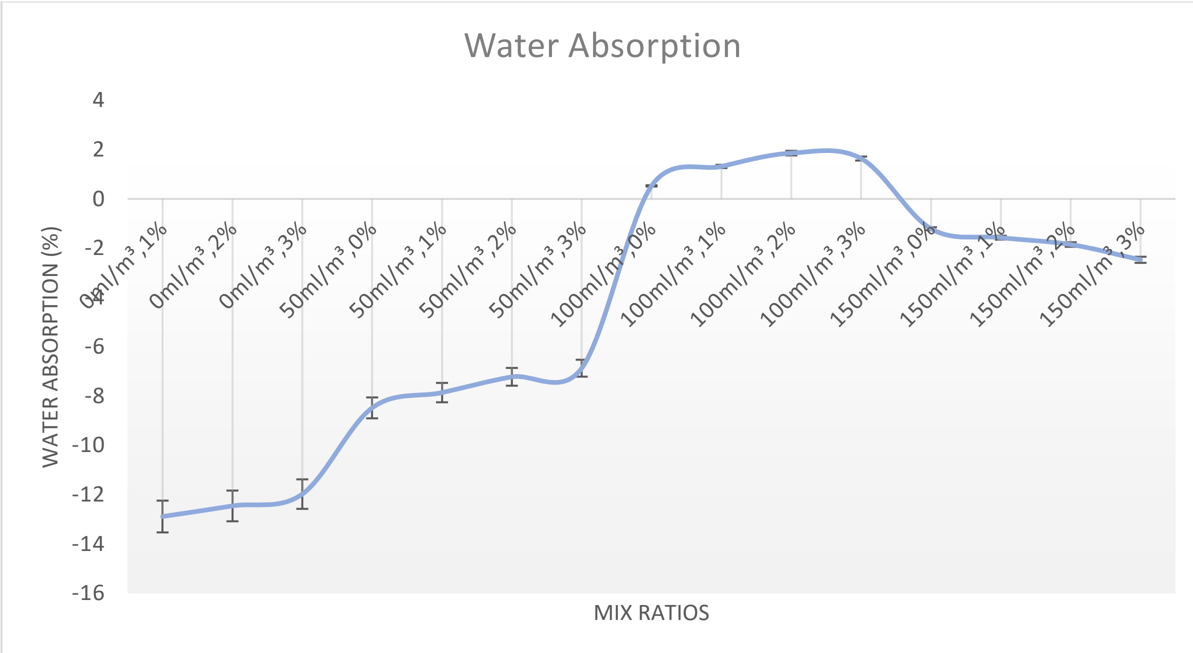


Figure 8 water absorption rate at different Bio enzyme and PALF ratios

Absorption of Water in Stabilized Bricks

The initial brick with no stabilization had a water absorption value of -14%, which indicates that it broke down severely when submerged in water. The high negative value indicates an actual loss in mass versus only water absorption, which are similar but are not true with this brick, showing it is structurally unsound.

After including Bio-Enzyme and PALF, the water absorption values were higher, indicating better stability. The intervention with PALF had no pronounced effects on the bricks, while Bio-Enzyme predominated in limiting brick disintegration due to their ability to mitigate water-stemming expansion.

(a) Bricks (0 ml/l Bio-Enzyme, 1%-3% PALF)

Mean Water Absorption: -12.89% to -11.98% (still breaking down).

- Bricks remained structurally unstable, but PALF reduced the loss of material due slightly to the addition of the PALF.
- PALF alone is not successful in reducing water resistance quite significantly.

Without Bio-Enzyme, the clay particle was loosely bonded, leaving it easily dispersible if it encounters water and lost its original form. PALF is not a stabilizer, and while it does stiffen the sample as a fiber reinforcement, it does not change the absorbent quality of clay.

(b) Bio-Enzyme Addition (50 ml/l Bio-Enzyme, 0%-3% PALF).

Mean Water Absorption: -8.48% to -6.87 %.

- There was a significant reduction in percentage disintegration compared to the unstabilized condition.
- PALF had minimal effects, with most of the improvement coming from Bio-Enzyme stabilization.

Bio-Enzyme altered the clay particle structure that gave it cohesion and reduced material loss, while the PALF did not enhance the ability of enhancing water absorption.

(c) Optimum Bio-Enzyme Stabilization (100 ml/l Bio-Enzyme, 0%-3% PALF).

Mean Water Absorption: 0.53% to 1.86 %.

- Observed major transition from disintegration (-14 % to 1.86 %).
- Full stabilization (positive values for water absorption) was achieved.
- While PALF still contributed very little, both conditions with and without PALF demonstrated similar trends.

Bio-Enzyme chemically altered the clay particles creating a strong bond reducing the retention of water. Formation of denser matrix significantly reduced water penetration.

(d) Excess Bio-Enzyme (150 ml/l Bio-Enzyme, 0%-3% PALF)- Over Stabilization

Mean Water Absorption: -1.21% to -2.47%

- Water absorption values became negative again, signifying a return to material disintegration.
- Instead of further improving water resistance, excess Bio-Enzyme destabilized the structure.

Too much Bio-Enzyme introduced excess charges, disrupting the electrostatic balance of clay particles, which led to over-lubrication that reduced inter-particle cohesion and made the bricks weak in wet conditions. PALF was unable to mitigate this effect since the instability was due to excess chemical modification rather than insufficient reinforcement.

Bio-Enzyme stabilization behaved significantly decreased disintegration with an optimal effect at 100 ml/l.

PALF did not have a major positive effect on water resistance, which suggests its role is more mechanical than chemically based.

Excess Bio-Enzyme (150 ml/l) leads to unintended destabilization leading to reduced water resistance.

Bricks with 100 ml/l Bio-Enzyme are the most water-resistant and durable for construction application.

COST BENEFIT ANALYSIS

Vol. of 1 brick = (0.215 x 0.1025 x 0.065)

= 0. 0.001432m^3

For 1000 bricks ≈ 1.432 m^3 ≈ 1.5 m^3

Bio-enzyme= 250,000/= per liter

For 150 ml = 37,550/= for 1.5 m^3 of bricks

PALF:

2,000/= for a sack of fresh leaves

1 sack gives approx. 1.6kg of fiber

Weight of 1000 bricks approx. = 3,000kg

2% of fiber = 60kg of fiber.

60kg of fiber = 75,000/=

Labor = 25,000/= per 1000 bricks

Total cost for 1000 bricks = 75,000 + 37,500 + 25,000

= 137,500/=

Cost per stabilized brick ≈ 140/=

VS

Cost per traditional burnt brick ≈ 250/=

4.4 DESIGN OF STABLIZED BRICK

Based on the analyzed results, a combination of a bio enzyme (Terrazyme) concentration of 100ml/m^3 is selected as the optimum concentration based on compressive strength and water absorption results achieved with Pineapple Leaf Fiber content of 2%.

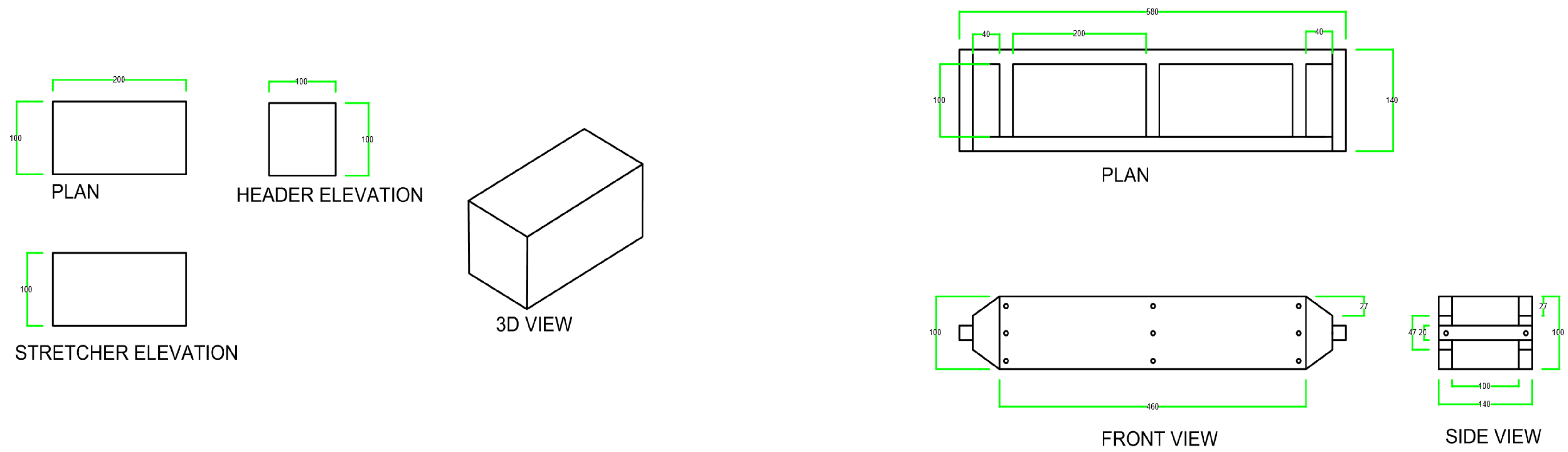
Table 9 Design Parameters

	Parameter	Result
100ml/m^3 Bio enzyme (Terrazyme)	Compressive Strength (Mpa)	3.1
	Water Absorption (%)	1.86

Table 10 Standard dimensions by UNBS

	Length	**Width**	**Thickness**
Standard Brick	210- 250mm	100- 130mm	70-100mm
Selected design	200	100	100

4.4.1 DESIGN OF CLAY BRICK AND WOODEN MOULD



PROJECT	THE USE OF A BIOENZYME AND PINEAPPLE LEAF FIBER AS A STABLIZER IN CLAY BRICKS.
STUDENT NAME	OCHOLLA COLLIN MIKE
SCALE	1:10
TITLE OF DRAWING	CLAY BRICK AND MOULD DESIGN

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The clay soils in Siron village, Kapchorwa District are highly expansive due to the high Free Swell Index (85.41%) and Plasticity Index (30%). And the bricks made from this soil are of strength of 1.7Mpa and 3.9 for the unfired and fired bricks respectively therefore, they do not meet the standards of min. of 2Mpa and 5Mpa respectively.

The fiber attained a tensile strength of *426 MPa* with an elongation of upto 6mm which indicated that the fiber had a great contribution in the compressive strength of the stabilized brick. However, the fiber alone has no significant effect on the reduction of water absorption but contributed to reduction of disintegration in the clay brick stabilization.

The stabilized brick attained a compressive strength of 3.1 Mpa which is >2Mpa standard for the unfired bricks. And the same stabilized brick also attained a reduction of disintegration from -14% to 1.86% and this best performance was attained at bio enzyme concentration of 100ml/m^3 and 2%. The stabilized brick showed a cheaper cost to make at UGX. 140 compared to the traditional fired bricks at UGX. 250 as of 2025 in Kapchorwa District.

5.2 Recommendations

Stabilization of clay bricks using the 100ml/m^3 bio enzyme and 2% PALF attains a compressive strength of up to 3.1Mpa which is still below the 5Mpa standards for a fired bricks therefore, further research can be done to enhance the brick strength to achieve >5Mpa compressive strength.

The Pineapple Leaf Fiber as a mechanical stabilizer with a tensile strength of 426Mpa is very expensive since it costs >50% of the total brick cost yet without significant contribution to the reduction of the rate of disintegration. Therefore, further research can be done on other cheaper and better performing alternative to PALF.

From this research conducted, the identified optimal ratio is 100ml/m^3 bio enzyme and 2% PALF and these attained a compressive strength of 3.1Mpa and water absorption of 1.86% with some degree of disintegration. Further research could be done to avoid any disintegration of the clay bricks. And more detailed analysis could be done to assess fiber interaction include SEM Analysis.

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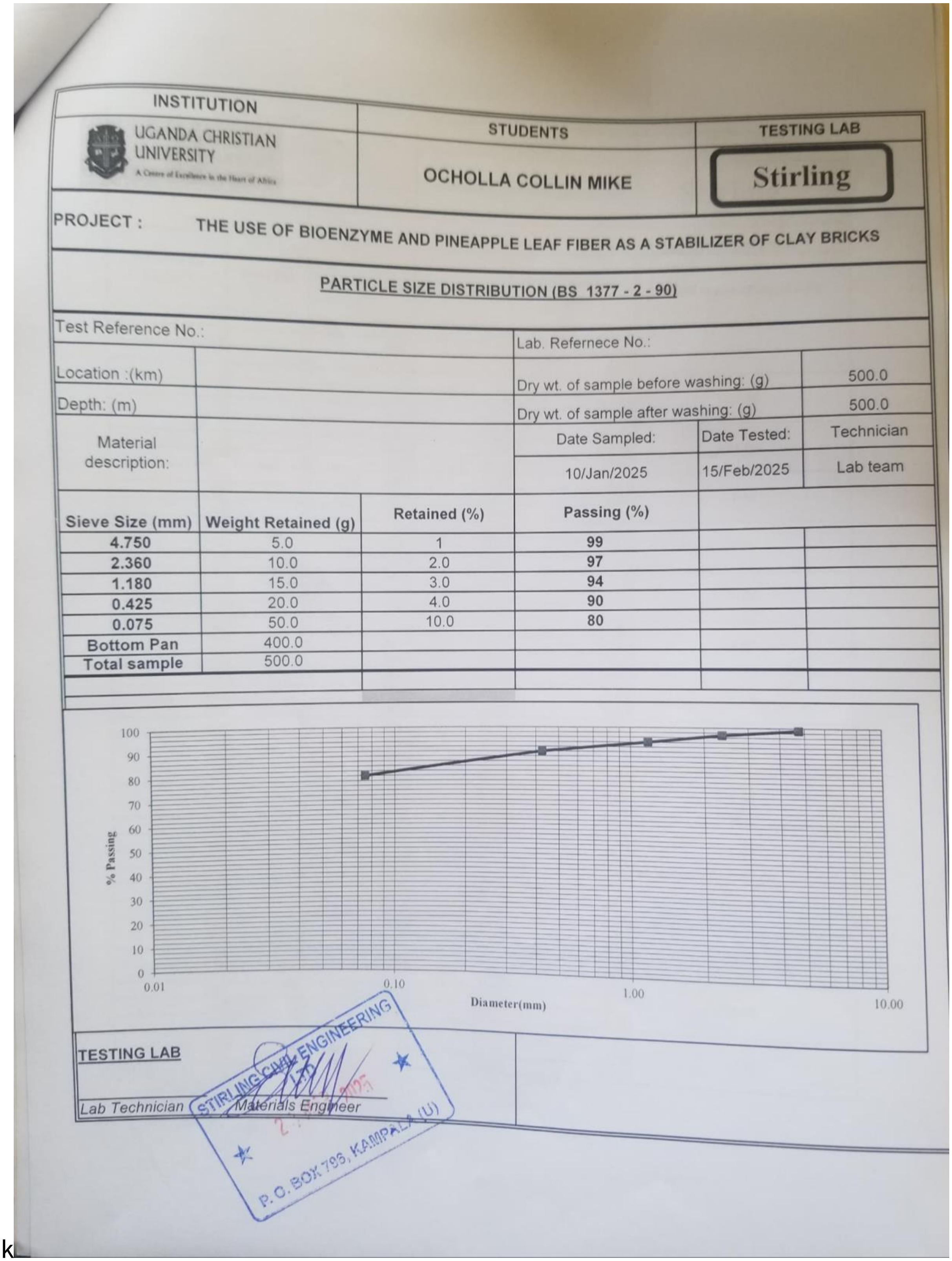
APPENDIX



INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	OCHOLLA COLLIN MIKE	Stirling

PROJECT : THE USE OF BIOENZYME AND PINEAPPLE LEAF FIBER AS A STABILIZER OF CLAY BRICKS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:		Lab. Refernece No.:		
Location :(km)		Dry wt. of sample before washing: (g)		500.0
Depth: (m)		Dry wt. of sample after washing: (g)		500.0
Material description:		Date Sampled:	Date Tested:	Technician
		10/Jan/2025	15/Feb/2025	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)		
4.750	5.0	1	99		
2.360	10.0	2.0	97		
1.180	15.0	3.0	94		
0.425	20.0	4.0	90		
0.075	50.0	10.0	80		
Bottom Pan	400.0				
Total sample	500.0				

TESTING LAB

Lab Technician Materials Engineer

STIRLING CIVIL ENGINEERING LTD
P.O. BOX 793, KAMPALA (U)

k

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	OCHOLLA COLLIN MIKE & SERIONI BRIAN	Stirling
PROJECT:	**THE USE OF BIOENZYME AND PINEAPPLE LEAF FIBER AS A STABILIZER OF CLAY BRICKS**	

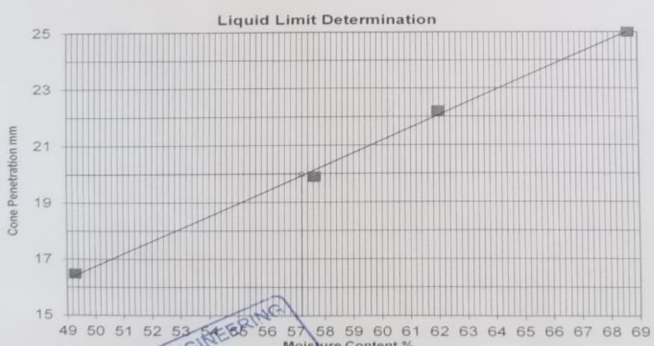
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Test Reference No.:	Lab. Reference No.:	Technician:	Lab Team
Location		Sample Date	17/Jan/2025
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	21/Jan/2025
LAYER	CLAY SAMPLE		

PLASTIC LIMIT	Test No.	KK	BA		Average
Mass of wet soil + container (g)		36.42	37.2		36.81
Mass of dry soil + container (g)		33.4	34.16		33.78
Mass of container (g)		22.26	23.13		22.695
Mass of moisture (g)		3.02	3.0		3.03
Mass of dry soil (g)		11.14	11.03		11.085
Moisture content %		27.1	27.6		27.3
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		16.5	19.9	22.2	25.0
penetration (mm)		16.5	19.9	22.2	25.0
AVERAGE		16.5	19.9	22.2	25.0
Container No.		A5	PIBO	AO	PI26
Mass of wet soil + container (g)		58.70	54.60	57.24	66.36
Mass of dry soil + container (g)		41.61	37.24	38.04	42.21
Mass of container (g)		6.94	7.12	7.05	7.04
Mass of moisture (g)		17.09	17.36	19.2	24.15
Mass of dry soil (g)		34.67	30.12	30.99	35.17
Moisture content (%)		49.3	57.6	62.0	68.7
AVERAGE		49.3	57.6	62.0	68.7



Liquid limit (%)	57.2
Plastic limit (%)	27.3
Plasticity Index (%)	29.9
Linear shrinkage	
Trough No.	4
Trough length (cm)	14.0
Specimen length (cm)	12.0
L.shringage =	2.0
% L.shrinkage =	14.3

Remarks:

TESTING LAB

Materials Engineer

Lab Technician

	OCHOLLA COLLIN MIKE & SERIONI BRIAN	TESTING LAB Stirling
PROJECT:	THE USE OF BIOENZYME AND PINEAPPLE LEAF FIBER AS A STABILIZER OF CLAY BRICKS	

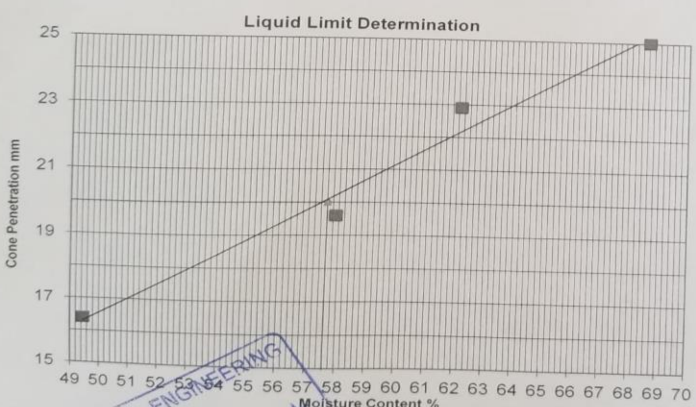
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Test Reference No.:			
Location	Lab. Reference No.	Technician:	Lab Team
Test method	0	Sample Date	17/Jan/2025
LAYER	BS 1377: Part 2, 1990:4.3/4.4	Test Date	21/Jan/2025
	CLAY SAMPLE		

PLASTIC LIMIT	Test No.	JL	DT		Average
Mass of wet soil + container (g)		38.29	40.15		39.22
Mass of dry soil + container (g)		34.9	36.37		35.635
Mass of container (g)		22.56	22.77		22.665
Mass of moisture (g)		3.39	3.8		3.585
Mass of dry soil (g)		12.34	13.6		12.97
Moisture content %		27.5	27.8		27.6
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		16.4	19.6	22.9	25.0
penetration (mm)		16.4	19.6	22.9	25.0
AVERAGE		16.4	19.6	22.9	25.0
Container No.		PI81	BE	A4	A6
Mass of wet soil + container (g)		58.66	48.92	58.30	73.09
Mass of dry soil + container (g)		41.62	33.52	38.62	46.14
Mass of container (g)		7.16	6.92	6.92	6.86
Mass of moisture (g)		17.04	15.4	19.68	26.95
Mass of dry soil (g)		34.46	26.6	31.7	39.28
Moisture content (%)		49.4	57.9	62.1	68.6
AVERAGE		49.4	57.9	62.1	68.6



Liquid limit (%)	57.6
Plastic limit (%)	27.6
Plasticity Index (%)	30.0
Linear shrinkage	
Trough No.	4
Trough length (cm)	14.0
Specimen length (cm)	12.0
L.shringage =	2.0
% L.shrinkage =	14.3

Remarks:

TESTING LAB

STIRLING CIVIL ENGINEERING LTD

P.O. BOX 796, KAMPALA (U)

Materials Engineer.

Lab Technician

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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 073/2025
21st March 2025

MR. OCHOLLA COLLIN MIKE
REG NO. S21B32/128
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-785-930312

REPORT OF ANALYSIS

Description of the Samples

One sample in a transparent polythene bag containing Clay soil sample was submitted by Mr. Ocholla Collin Mike, on 17th March 2025, and analysed on 20th March 2025. A summary of the sample received is shown in table below

S/N	Description	Quantity	Assigned Lab ID
1	Clay soil substances packed in a transparent polythene bag.	01	Sample "A" DFD 073/2025

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 073/2025 Clay sample
Silicon dioxide	% m/m	48.27
Aluminum Oxide	% m/m	20.53
Iron (III) Oxide	% m/m	10.18
Calcium Oxide	% m/m	7.32
Magnesium oxide	% m/m	4.22
Potassium Oxide	% m/m	3.56
Sodium oxide	% m/m	2.87
Titanium di oxide	% m/m	1.23
Manganese oxide	% m/m	0.85
Copper oxide	% m/m	0.29

Remarks

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

Fwd- 21st/03/25

Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

INSTITUTION

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	OCHOLLA COLLIN MIKE & SERIONI BRIAN	Stirling
PROJECT	THE USE OF BIOENZYME AND PINEAPPLE LEAF FIBER AS A STABILIZER OF CLAY BRICKS	

DETEMINATION OF FREE SWELL INDEX

LOCATION: MUKONO LAB		TECHNICIAN	Lab Team
STRUCTURE:	CLAY SOIL	SAMPLE No.	
		Date Sampled:	UNKNOWN
Test method:	ASTM D720	Date Tested:	28/Jan/25

Sample ID	Mass of Dry Soil Passing 425µ sieve (gm)	Volume in water after 24 hrs swell (Vd)	Volume of water Kerosene after 24 hrs swell (Vk)	Free Swell Index(FSI %) (((Vd-Vk)/Vk)x100
1	10	20.7	11.5	80.00
2	10	21.5	11.2	91.96
3	10	19.9	10.8	84.26
erage swell index				85.41

FOR TESTING LAB

LAB TECHNICIAN	MATERIALS ENGINEER	

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INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	OCHOLLA COLLIN MIKE & SERIONI BRIAN	Stirling
PROJECT	THE USE OF BIOENZYME AND PINEAPPLE LEAF FIBER AS A STABILIZER OF CLAY BRICKS	

COMPRESSIVE STRENGS FOR BRICKS

LOCATION:	MUKONO LAB
STRUCTURE:	BRICKS
CLASS OF BRICK	

TECHNICIAN	Stirling lab
SAMPLE No.	
Lab. Ref. No	
Date Casted:	5/Nov/24
Date Crushed:	14/Jan/25

CASTING DATE	CRUSHING DATE	WT OF CUBES (gm)	DIMENSION (mm)	DENSITY KG/M^3	AGE	CRUSHING LOAD(KN)	ULTIMATE COMP. STRENGTH (Mpa)	AVERAGE STRENGTH(Mpa)
FIRED BRICKS								
05/11/2024	14/Jan/25	3315	198 X98.2X 104.5	1.632	unknown	70	3.6	3.9
	14/Jan/25	3470	198 X98.2X 104.5	1.708		85	4.4	
	14/Jan/25	3539	198 X98.2X 104.5	1.742		75	3.9	
UN FIRED BRICK								
	14/Jan/25	4232	198 X98.2X 104.5	2.083	unknown	40	1.8	1.7
	14/Jan/25	4190	198 X98.2X 104.5	2.062		35	1.6	
5/Nov/24	14/Jan/25	4080	198 X98.2X 104.5	2.008		40	1.8	

FOR TESTING LAB

LAB TECHNICIAN

MATERIALS ENGINEER

STIRLING CIVIL ENGINEERING LTD

KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	OCHOLLA COLLIN MIKE & SERIONI BRIAN	Stirling

PROJECT THE USE OF BIOENZYME AND PINEAPPLE LEAF FIBER AS A STABILIZER OF CLAY BRICKS

SUMMARY OF WATER ABSOPTION RESULTS

LOCATION: MUKONO LAB

STRUCTURE: BRICKS

SSD WGHT	OVEN DRY	WATER ABSORPTION %
FIRED BRICKS		
4766	3972	7.9
4078	3329	7.5
4481	3734	7.5
AVERAGE		7.6
UN FIRED BRICK		
2705	4097	-13.9
2773	4171	-14.0
2645	4057	-14.1
AVERAGE		-14.0
Remarks		

TESTING LAB

LAB TECHNICIAN

STIRLING CIVIL ENGINEERING LTD P.O. BOX 286, KAMPALA (U)

LAB ANALYSIS REPORT FOR BRIAN SERIONI STUDENT FROM UGANDA CHRISTIAN UNIVERSITY

Test serial number: T001/2025

Received on: 31/01/2025

Name of client: BRIAN SERIONI

Prepared by:

Tukashaba Annitah (Polymer, Textile and Industrial Engineer) 05/02/2025

Nayebare Peace (Polymer, Textile and Industrial Engineer) 5/02/25.

cc;

Solomon Kiiza (Head of Textiles, Polymer and Materials Technologies) 5/02/2025

Prepared for BRIAN SERIONI

5TH FEBRUARY, 2025

UGANDA INDUSTRIAL RESEARCH INSTITUTE
UIRI
05 FEB 2025
P.O. BOX 7086, KAMPALA

Introduction

Pineapple Leaf Fibres were delivered to the lab for analysis on the 31st January, 2024.

These were subjected to the following tests.

- Breaking force
- Elongation
- Fiber strength (RKM- resistance per kilo meter)

Purpose of the analysis

To ensure the Pineapple Leaf Fibres fit the intended purpose.

Tabulated results tested in accordance to ASTM D2256

Tests	Breaking force (gf)	Elongation (mm)	RKM (g/tex)	Breaking work (gf*cm)	Time to break (s)
1	179.31	7.80	8.41	74.80	0.94
2	166.93	4.65	7.83	37.67	0.56
3	161.97	6.15	7.60	51.71	0.74
4	181.78	4.80	8.53	45.93	0.58
5	157.02	6.60	7.37	54.17	0.79
Average	**169.40**	**6.00**	**7.95**	**52.86**	**0.72**

Note

A minimum of three (3) sample results were considered as per standard requirement.

UGANDA INDUSTRIAL RESEARCH INSTITUTE
UIRI
05 FEB 2025
P.O. BOX 7086, KAMPALA

UGANDA INDUSTRIAL RESEARCH INSTITUTE.,
Kampala Business Park - Namanve
P.O Box 7086,
Kampala.,UGANDA

TensoMaster
Version 3.1.5

MAG

Single Yarn Test Report

Test ID	: TM-000263	Material Type	: Pineapple fibers	RH	: 63.07 %
Department	: TEXTILE	Yarn Spec.	: 21.31/1 Tex	Temperature	: 27.80 °C
Machine No.	: 1	Pre-tension	: 10.65 Grams	Sample(s)	: 1
Lot No.	: -	Gauge Length	: 830 mm	Readings / Sample	: 5
Shift	: General	Test Speed	: 500 mm/min.	Date	: 04-02-2025
Operator	: OSBERT	Clamp Pressure	: 4.20 bar	Time	: 12:41:17 pm

Client/party : Pineapple leaf fibers tested for tensile properties
Remarks : Brian Serioni UCU student
Limits : -

Single Test Results :
Sample:1

Tests	B-Force (gf)	Elongation (mm)	RKM (g/tex)	B-Work (gf*cm)	T- Break (s)
1	179.31	7.80	8.41	74.80	0.94
2	*166.93	*4.65	7.83	37.67	0.56
3	*161.97	6.15	7.60	51.71	0.74
4	181.78	*4.80	8.53	45.93	0.58
5	*157.02	6.60	7.37	54.17	0.79
Average	169.40	6.00	7.95	52.86	0.72
CV %	6.37	21.87	6.37	26.13	
Minimum	157.02	4.65	7.37	37.67	0.56
Maximum	181.78	7.80	8.53	74.80	0.94
Range	24.76	3.15	1.16	37.13	
SD	10.79	1.31	0.51	13.81	
Q95(±)	12.41	1.51	0.58	15.88	
Q99(±)	19.46	2.37	0.91	24.91	

Weak Places : BF = 0, BE = 0, BF+BE = 0

Strong Places : BF = 0, BE = 0, BF+BE = 0

* - Out Lier Results :

	B-Force(gf) - 1%		Elongation(mm) - 1%
Total :	3	Total :	2
Average :	161.97	Average :	4.73
CV% :	3.06	CV% :	2.24

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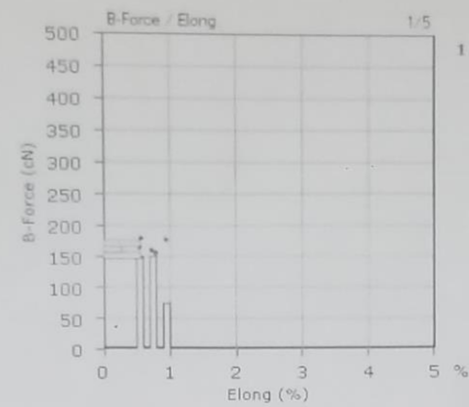
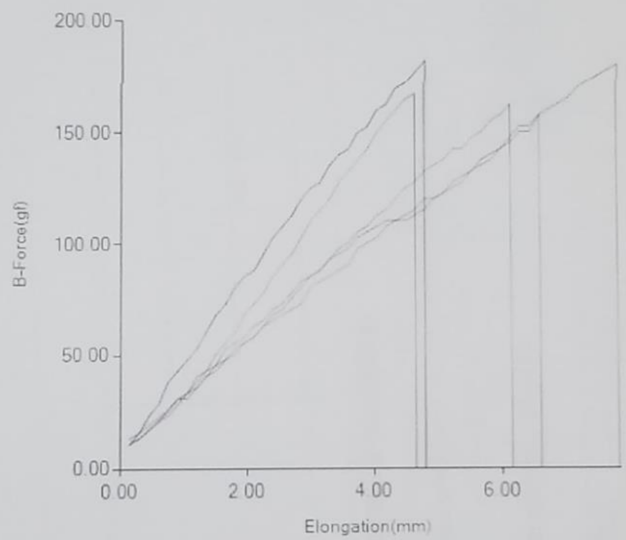


FE Curve



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Approved By

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INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	OCHOLLA COLLIN MIKE (S21B32/128)	Stirling
PROJECT	THE USE OF BIOENZYME AND PINEAPPLE LEAF FIBER AS A STABILIZER OF CLAY BRICKS	

COMPRESSIVE STRENGS FOR BRICKS

LOCATION: MUKONO LAB		TECHNICIAN	Stirling lab
STRUCTURE:		SAMPLE No.	
CLASS OF BRICK		Lab. Ref. No	
		Date Casted:	1/Mar/25
	BRICKS	Date Crushed:	8/Mar/25

Bio-Enzyme (ml/m³)	PALF (%)	WT OF BRICK (gm)	DIMENSION (mm)	DENSITY KG/M³	AGE	CRUSHING LOAD(KN)	ULTIMATE COMP. STRENGTH (Mpa)
			FIRED BRICKS				
0	1	3090	215.0 × 102.5 × 65.0	1.521	7	24.24	1.2
0	2	3045	216.2 × 102.3 × 65.1	1.499		26.54	1.4
0	3	3100	217.4 × 101.8 × 65.9	1.526		26.56	1.4
50	0	3150	214.7 × 103.1 × 64.3	1.550		28.78	1.5
50	1	3030	215.5 × 102.7 × 64.8	1.491		30.98	1.6
50	2	3030	216.1 × 103.0 × 64.5	1.491		33.39	1.7
50	3	3160	217.0 × 101.9 × 65.7	1.555		35.38	1.8
100	0	3080	213.8 × 104.2 × 63.4	1.516		35.64	1.8
100	1	3025	214.6 × 103.5 × 64.1	1.489		37.76	1.9
100	2	3095	215.3 × 102.6 × 64.9	1.523		41.97	2.2
100	3	3025	216.8 × 101.7 × 65.8	1.489		44.1	2.3
150	0	3025	212.9 × 105.3 × 63.2	1.489		42.59	2.2
150	1	3060	213.5 × 104.7 × 63.9	1.506		38	2.0
150	2	2950	215.0 × 103.2 × 64.7	1.452		35.5	1.8
150	3	2995	217.2 × 102.4 × 65.5	1.474		31.14	1.6

FOR TESTING LAB

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MATERIALS ENGINEER

LAB TECHNICIAN

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	OCHOLLA COLLIN MIKE (S21B32/128)	Stirling

PROJECT	THE USE OF BIOENZYME AND PINEAPPLE LEAF FIBER AS A STABILIZER OF CLAY BRICKS

COMPRESSIVE STRENGS FOR BRICKS

LOCATION: MUKONO LAB		TECHNICIAN	Stirling lab
STRUCTURE:		SAMPLE No.	
CLASS OF BRICK		Lab. Ref. No	
		Date Casted:	1/Mar/25
	BRICKS	Date Crushed:	15/Mar/25

Bio-Enzyme (ml/m³)	PALF (%)	WT OF BRICK (gm)	DIMENSION (mm)	DENSITY KG/M^3	AGE	CRUSHING LOAD(KN)	ULTIMATE COMP. STRENGTH (Mpa)
FIRED BRICKS							
0	1	3074	214.5 × 103.0 × 64.8	1.513	14	30.93	1.1
0	2	3043	216.8 × 102.1 × 65.3	1.498		35.44	1.2
0	3	3082	217.9 × 101.5 × 66.2	1.517		37.57	1.2
50	0	3126	213.9 × 104.0 × 63.7	1.538		37.78	1.3
50	1	3038	215.2 × 102.9 × 65.0	1.495		42.02	1.4
50	2	3038	216.5 × 103.4 × 64.4	1.495		44.75	1.5
50	3	3128	217.1 × 101.8 × 65.9	1.539		46.2	1.6
100	0	3088	212.7 × 105.0 × 63.5	1.520		51.34	1.6
100	1	3026	214.8 × 103.7 × 64.3	1.489		53.42	1.7
100	2	3077	215.6 × 102.5 × 65.2	1.514		59.83	1.9
100	3	3026	216.9 × 101.9 × 65.6	1.489		59.86	2.0
150	0	3026	213.2 × 104.8 × 63.9	1.489		58.07	1.9
150	1	3062	214.4 × 103.9 × 64.2	1.507		51.2	1.7
150	2	2954	215.7 × 102.8 × 64.6	1.454		46.37	1.6
150	3	2963	217.3 × 102.2 × 65.4	1.458		42.2	1.4

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INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	OCHOLLA COLLIN MIKE (S21B32/128)	Stirling

PROJECT	THE USE OF BIOENZYME AND PINEAPPLE LEAF FIBER AS A STABILIZER OF CLAY BRICKS

COMPRESSIVE STRENGS FOR BRICKS

LOCATION: MUKONO LAB		TECHNICIAN	Stirling lab
STRUCTURE:		SAMPLE No.	
CLASS OF BRICK		Lab. Ref. No	
		Date Casted:	22/Feb/25
	BRICKS	Date Crushed:	22/Mar/25

Bio-Enzyme (ml/m³)	PALF (%)	WT OF BRICK (gm)	DIMENSION (mm)	DENSITY KG/M³	AGE	CRUSHING LOAD(KN)	ULTIMATE COMP. STRENGTH (Mpa)
FIRED BRICKS							
0	1	3120	214.3 × 102.8 × 64.7	1.536	28	41.83	1.9
0	2	3040	216.5 × 102.2 × 65.2	1.496		44.26	2.0
0	3	3090	217.8 × 101.6 × 66.1	1.521		46.23	2.1
50	0	3150	213.7 × 103.9 × 63.8	1.550		48.85	2.2
50	1	3025	215.1 × 102.7 × 64.9	1.489		53.06	2.4
50	2	3035	216.4 × 103.3 × 64.5	1.494		58.11	2.6
50	3	3160	217.2 × 101.7 × 65.8	1.555		59.89	2.7
100	0	3080	212.5 × 105.1 × 63.6	1.516		62.49	2.8
100	1	3005	214.7 × 103.6 × 64.4	1.479		64.51	2.9
100	2	3075	215.9 × 102.4 × 65.1	1.513		68.5	3.1
100	3	3010	216.6 × 101.9 × 65.7	1.481		66.28	3.0
150	0	2995	213.1 × 104.9 × 63.8	1.474		64.77	2.9
150	1	3060	214.3 × 103.8 × 64.1	1.506		62.18	2.8
150	2	2950	215.6 × 102.9 × 64.5	1.452		57.66	2.6
150	3	2975	217.7 × 102.1 × 65.3	1.464		53.3	2.4

FOR TESTING LAB

LAB TECHNICIAN

MATERIALS ENGINEER

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	OCHOLLA COLLIN MIKE S21B32/128	Stirling

PROJECT: THE USE OF BIOENZYME AND PINEAPPLE LEAF FIBER AS A STABILIZER OF CLAY BRICKS

Bio-Enzyme (ml/m^3)	PALF (%)	Initial Weight (g)	Final Weight (g)	Water Absorption (%)	MEAN Water Absorption (%)
0	1	2986	2605	-12.79	
0	1	2967	2586	-12.88	-12.89
0	1	3094	2693	-13.01	
0	2	2928	2562	-12.45	
0	2	3067	2680	-12.64	-12.46
0	2	3024	2653	-12.29	
0	3	2917	2567	-12.04	
0	3	2994	2639	-11.88	-11.98
0	3	3078	2706	-12.02	
50	0	3064	2806	-8.44	
50	0	3120	2858	-8.43	-8.48
50	0	3027	2769	-8.58	
50	1	3270	3015	-7.83	
50	1	2926	2695	-7.9	-7.86
50	1	2968	2737	-7.84	
50	2	2995	2778	-7.18	
50	2	2887	2678	-7.3	-7.22
50	2	3083	2861	-7.17	
50	3	3072	2860	-6.88	
50	3	3002	2796	-6.84	-6.87
50	3	2957	2754	-6.9	
100	0	2880	2895	0.53	
100	0	2937	2953	0.56	0.53
100	0	3060	3076	0.51	
100	1	2983	3026	1.46	
100	1	2966	3003	1.27	1.32
100	1	3040	3078	1.24	
100	2	3093	3151	1.88	
100	2	3021	3072	1.72	1.86
100	2	3025	3085	1.98	
100	3	3110	3155	1.42	
100	3	3014	3068	1.79	1.64
100	3	2975	3026	1.7	
150	0	3054	3016	-1.27	
150	0	2979	2940	-1.35	-1.21
150	0	2971	2943	-1.02	
150	1	3102	3054	-1.58	
150	1	2977	2931	-1.58	-1.57
150	1	2788	2745	-1.56	
150	2	3028	2972	-1.9	
150	2	2968	2916	-1.78	-1.85
150	2	2977	2921	-1.88	
150	3	3036	2964	-2.37	
150	3	2987	2911	-2.46	-2.47
150	3	3017	2940	-2.58	

Testing Lab

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Materials Engineer

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MAR 2025

Figure 10 molding stabilized bricks

Figure 9 mixing of Bio enzyme in required ratios

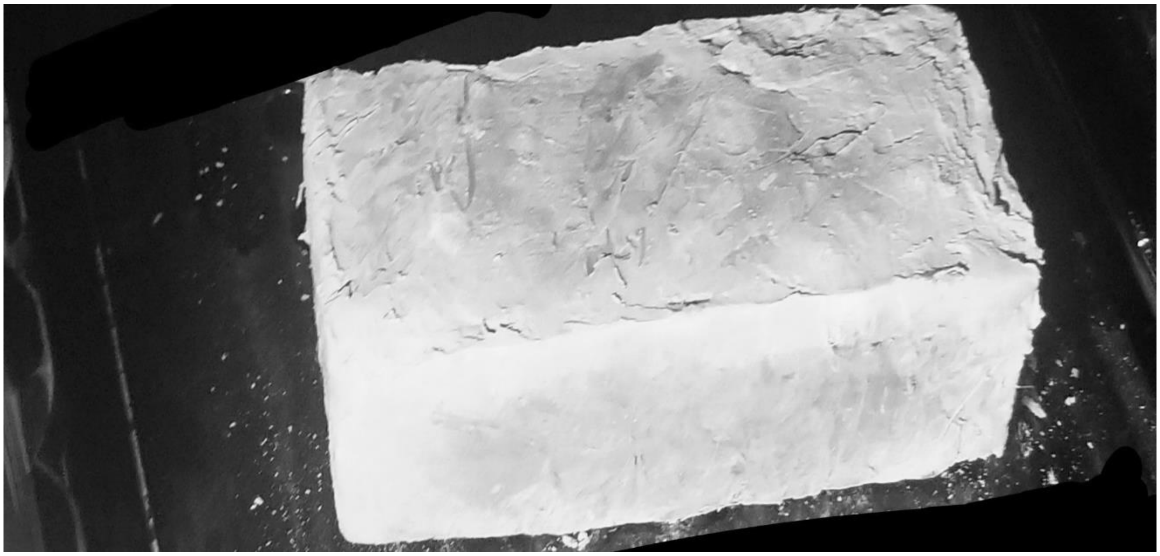

Figure 12 drying stabilized brick

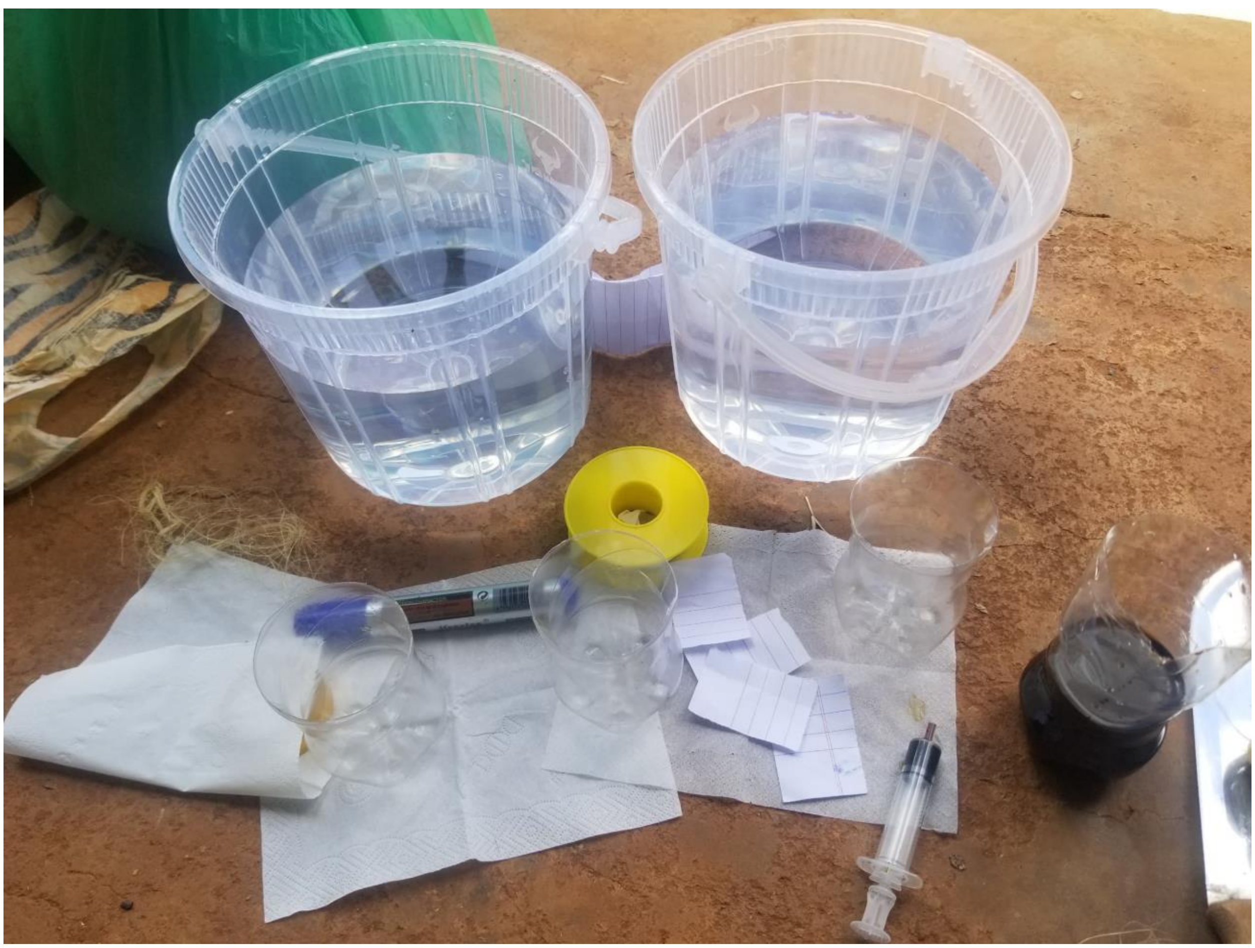

Figure 11 bio enzyme and proportioning containers

Figure 13 Mold making

Figure 14 Designed Brick Mold

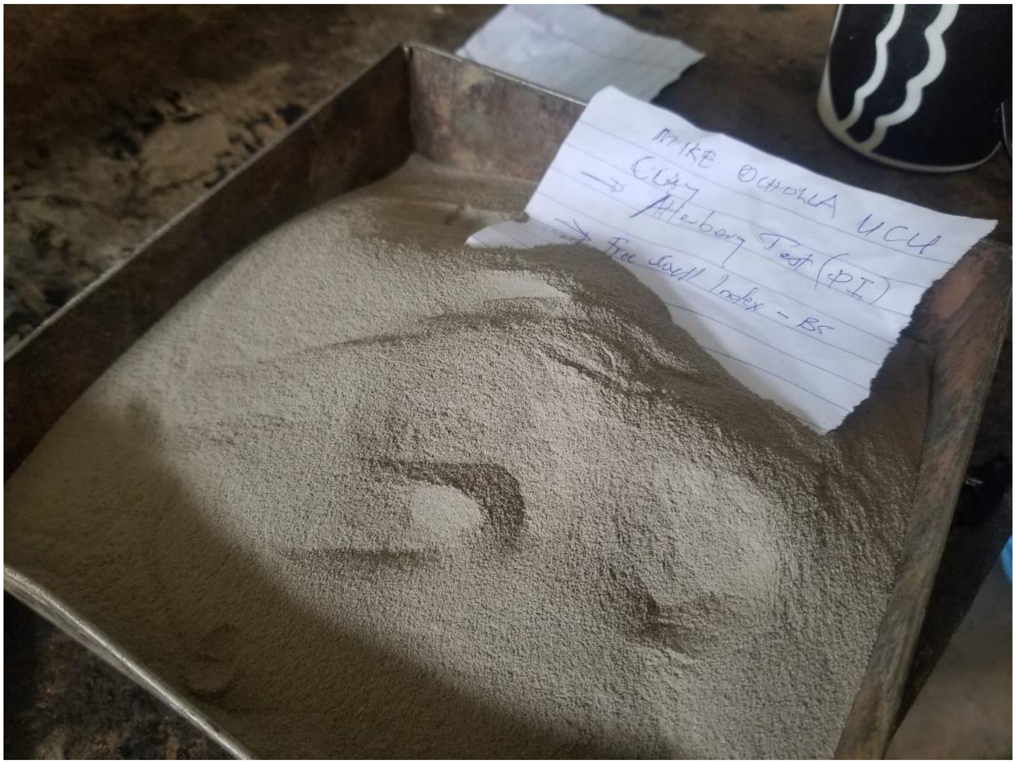

Figure 16 Failed unburnt clay brick in water absorption test

Figure 15 Compressive strength test

Figure 17 Failed Unfired clay bricks in water absorption test

Figure 18 clay soil Preparation for Sieve Analysis

Figure 19 PALF extraction

COMPLIANCE MATRIX	
COMMENT	**COMPLIANCE**
How were the fibers prepared	See Pg. 15 and 16
Improve the recommendation and conclusion	See Pg. 45 and 46
Improve the design and the engineering drawings	See Pg. 42,43 and 44
Carry out SEM analysis to check the fiber matrix interaction	See Pg. 46