THE USE OF A BIO-ENZYME AND PINEAPPLE LEAF FIBRE IN THE STABILIZATION OF CLAY BRICKS :A CASE STUDY OF SIRON CLAY LOCATED IN SIRON VILLAGE IN KIRWOKO PARISH OF KAPTANYA SUBCOUNTY, KAPCHORWA DISTRICT UGANDA

BRIAN SERIONI

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ABSTRACT

The growing demand for affordable and sustainable building materials in Uganda, coupled with increasing environmental concerns, has prompted the need to explore alternative methods of clay brick stabilization. Conventional clay bricks are typically fired using firewood, a practice that contributes heavily to deforestation, carbon emissions, and other forms of environmental degradation. This research investigates the feasibility of using a hybrid stabilization method involving a bio-enzyme (Terrazyme) and pineapple leaf fiber (PALF) to improve the engineering properties of clay bricks while minimizing ecological impact.

The study was conducted using high plasticity clay obtained from Siron Village, Kirwoko Parish in Kaptanya Subcounty, Kapchorwa District. The clay soil underwent a series of laboratory tests, including particle size distribution, Atterberg limits, compaction, compressive strength, shrinkage, and water absorption tests in accordance with British Standards. PALF was extracted from agricultural waste, characterized through tensile strength analysis, and evaluated for reinforcement suitability. Terrazyme was produced through a controlled fermentation process and tested for pH, viscosity, and concentration.

Experimental brick samples were prepared using varying proportions of PALF (2%–6%) and Terrazyme (0%–5%) by weight and volume respectively. Among all the combinations, the optimal mix—2% PALF and 100 ml/m^3 of Terrazyme—produced unfired bricks with the best performance. These bricks achieved a compressive strength of 2.7 MPa, which is significantly higher than that of untreated bricks, and

showed a 15% reduction in water absorption and 30% reduction in linear shrinkage. The hybrid stabilization not only enhanced strength and dimensional stability but also improved durability by reducing moisture susceptibility and potential for cracking.

The results of this research confirm that hybrid stabilization using bio-enzymes and natural fibers can produce structurally sound, cost-effective, and environmentally sustainable clay bricks without the need for high-temperature firing. This technique holds great potential for application in rural housing, eco-construction, and lowincome settlements across Uganda. Moreover, the use of locally available materials such as pineapple leaves promotes circular economy practices and reduces agricultural waste. The study concludes by recommending further field trials, scaleup studies, and long-term performance evaluations under various climatic conditions to establish the method as a mainstream construction practice.

DECLARATION

I Serioni Brian hereby declare that this research proposal is my original work and has never been submitted to any institution for any award. Any other sources of information referred to are herein duty acknowlwdged.

Sign…………………………….. Date……………………… 17-4-25

APPROVAL

This is to certify that this research titled, Use of a bio-enzyme and pineapple leaf fiber as a stabilizer of clay bricks was carried out under my supervision as the academic supervisor and is now ready for submission for examination.

Eng. Dr. Oleng Morris

Signature: ……………………… Date: ……………………………………

Supervisor.

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PALF – Pineapple Leaf Fiber

FSI – Free Swell Index

MDD – Maximum Dry Density

OMC – Optimum Moisture Content

MPa – Megapascal

% – Percentage

BS – British Standard

PLA – Polylactic Acid

UIRI – Uganda Industrial Research Institute

SCL – Stirling Construction Laboratories

GAL – Government Analytical Laboratories

LL – Liquid Limit

PL – Plastic Limit

PI – Plasticity Index

TBC – Terminal Brick Compressive Strength

CBR – California Bearing Ratio

PVC – Polyvinyl Chloride

RKM – Strength per Tex (Relative Tenacity)

B-Force – Breaking Force

B-Work – Breaking Work

T-Break – Break Time

CHAPTER I: INTRODUCTION

1.1 Background and Introduction

Like most developing countries, Uganda has a large housing deficit contributed by its rapid growth in population and urbanization. Clay bricks remain among the most widely applied building materials within both rural and urban areas, mostly because of their comparatively lower costs and higher accessibility. Most of this production is at a small scale and in places like Siron, where high plasticity clay is locally available. Such clay must be stabilized to enhance its strength and durability.

These are typically fired with firewood, which is very energy-intensive and destructive to the environment. Relating to this, it contributes to deforestation, which means loss of biodiversity, soil erosion, and also causes a high rate of carbon dioxide emission. According to a report by Bodipo-Memba et al., 2022, it is stated that Uganda loses its forests annually by 1.8%, proportionately with a higher part of this deforestation mainly belongs to the collection of fuelwood for brick kilns. If that wasn't enough, high-plasticity clays rich in montmorillonite, such as in Mukono for example, bring additional troubles: these soils swell with increase in water content and shrink with decrease, thus they do not present structural stability unless better stabilized. As said, increased firing resolves this, but the environmental and financial costs of brick kilns are very high. Application of firewood-saving alternative stabilization methods thus stands as a pressing need.

The application of bio-enzyme technology, alongside the utilization of agricultural byproducts such as pineapple leaf fiber, is gaining recognition as a sustainable method to improve the resilience and structural integrity of clay bricks, concurrently reducing environmental repercussions (Saini & Vaishnava, 2015).

Although it populates the places with intensive pineapple culture, pineapple leaf fiber is regarded as a waste product. While it has very good tensile strength and binding properties, using it as reinforcement material in the construction industries is worth the result it has shown in tests. Razman et al., 2024 The current work represents an ecologically friendly method of using a bio-enzyme coupled with stabilisation, which is the use of PALF for solving problems with plasticity in clay soil, reduction in various environmental crises connected with traditional production methods of bricks.

1.2 Problem Statement

The Ugandan manufacturing of clay bricks is so dependent on firewood; this enhances deforestation and environmental degradation. According to the

Ministry of Water and Environment of Uganda as cited by Bodipo-Memba et al. 2022, it is estimated that about 70% of energy that is used in brick kilns is firewood, costing about 92,000 hectares of forest loss annually.

Besides just accelerating this process of deforestation, it also emits a lot of carbon dioxide into the atmosphere, hence contributing to the climate crisis. With increased expansion in the brick-making industry, Uganda is getting increasingly unsustainable and inching closer to an ecological disaster. In addition, conventional clay bricks, specifically made from smectite clays found in eastern Uganda, precisely in Budadiri, Chelel, Mutufu, and Siron areas, have insufficient mechanical strength. Smectite clays, having high acidities with values between 0.1 and 1.85 mol/g, with compositions of 40-50% smectite, 2030% being the feldspars component, and other element makeups like iron, aluminum, and silicon being 11%, 18%, and 60%, respectively, perform moderately, with high absorption of water to yield bricks that are weak and brittle (Wasajja-Navoyojo et al., 2016; Mukasa-Tebandeke et al., 2015).

The mean compressive strength for these conventional bricks range between 0.36 and 1.2 MPa, a measure below the standards in global construction standards according to MukasaTebandeke et al. 2014.

Lime and cement have conventionally been used as additives to improve brick standards; however, their production is highly energy-intensive and one of the major contributors to green house gases. For instance, cement industries alone contribute about 8% to global carbon emissions (Andrew, 2019). There thus is an urgent need for environmentally friendly products that will help in stabilizing clay bricks without reliance on high-energy materials like cement and lime.

The bio-enzymatic treatments may increase the cohesion in soils, decrease the permeability, and enhance compressive strength of clays by ion exchange reaction mechanisms which favored the development of stable aggregates. According to Saini & Vaishnava, 2015, bioenzyme-treated bricks demonstrated better compressive strength of as high as 4 MPa compared with conventional bricks. Addition of PALF, a full natural resource in Uganda, improves significantly the mechanical properties of the clay bricks. Presence of PALF improves the tensile strength and durability in the composites hence an ideal material for reinforcement in bricks. This paper tries to integrate the use of bio-enzymes and PALF in the production of bricks with the aim of attaining environmental sustainable stabilization methods that reduce reliance on kiln firing, environmental degradation and enhances the mechanical efficiency of the fired clay bricks.

Bricks with increased compressive strength and improved on water absorption, and with an increased life compared to the traditional method, are expected.

This work, therefore, investigates the application of bio-enzyme and pineapple leaf fibers as additives for stabilization in clay bricks.

1.3 Main Objective of the Study

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

1.3.1 Specific Objectives

1. To determine the soil properties of the clay brick.

2. To determine the chemical properties of the bio-enzyme and physical properties of pineapple leaf fibers.

3. To identify the optimal ratio of bio-enzyme and pineapple leaf fiber for effective clay brick stabilization.

4. To evaluate the engineering properties of stabilized clay bricks.

1.3.2 Investigative Questions

1. What soil characteristics are most closely related to clay bricks?

2. What is the biochemical nature of bio-enzymes, and what is the physical property of pineapple leaf fibers?

3. What is the best ratio between the bio-enzyme and pineapple leaf fiber to stabilize clay bricks?

4. What are the engineering properties of pineapple leaf fibers-added clay bricks treated with bio-enzyme?

1.4 Justification

The soils mainly consist of Montmorillonites in the Siron Village of Kirwoko Parish, Kaptanya Subcounty, Kapchorwa District. These clay soils are clayey in nature and have similar mechanical properties to those of the Kaolinite group in regards to swelling. It means that they have ability of exchange cations so cations are well bonded to water which is the reason why these clays increase and expand following the adsorbed water content increase.

Bioenzymes particularly terrazyme, which is any organic, non-toxic formulation resulting from the fermentation of fruits and vegetables residues, have the capacity to enhance the engineering properties of soil improvements by mobilising enormous quantities of soil and cation structure on a particlebasis in the soil, reducing hydration and increasing definable strength (Shah,

2017; Suresh, 2017). Some studies on the effect of Terrazyme on the California Bearing Ratio of the soil at different Terrazyme dosages have shown very good improvement in the strength of the soil, with 0.5 ml solution per 100 ml of water as the best dose (Suresh, 2017; Panchal, 2017). Treatment with chemicals helps increase the strength of the soil, reduce the thickness of the pavement and allows a 30% reduction on the cost of building roads (Suresh, 2017). This method is an efficient way of stabilizing the soil without damaging the nature and is extending to all activities especially in the geo-technical applications.

The fiber of pineapple leaf (PALF) has also been used to good results in the reinforcement of clay and earth bricks. Encouraging mechanical properties have also been realized with pineapple leaf fiber (PLF) and for a range of applications. Composites based on PLF/PLA showed good strength, which varies from 16.71 MPa to 76.47 MPa depending on the matrix and fiber content. The optimum amount of fibers required for the mechanical properties is usually in the order of 30-40% (Susilowati & Sumardiyanto, 2018; Odusote & Kumar, 2016).

1.5 Significance of the Study

This study holds great significance for both the local community in Siron Village, Kirwoko Parish, and the broader construction and environmental sectors. The clay soils in this region, rich in Montmorillonites, exhibit characteristics such as swelling due to their high cation exchange capacity and water retention properties. These traits often lead to structural challenges in traditional clay bricks, reducing their durability and reliability. Therefore, there is a pressing need for a more sustainable and robust method of clay brick stabilization to improve the quality of construction materials.

The integration of bio-enzyme, specifically Terrazyme, and pineapple leaf fibers (PALF) offers an innovative approach to soil stabilization. Terrazyme, a non-toxic organic formulation derived from the fermentation of fruit and vegetable residues, has been shown to significantly enhance the engineering properties of soils. Studies have demonstrated that Terrazyme improves soil strength by mobilizing cations and reducing hydration, making it a promising agent for stabilizing clay bricks (Shah, 2017; Suresh, 2017). The ability to strengthen soil without harming the environment provides a crucial alternative to conventional stabilization techniques, especially in rural areas like Siron Village. Furthermore, the cost-effectiveness of this method, with potential savings of up to 30% in construction costs, makes it an attractive solution for low-income communities (Suresh, 2017).

In addition, pineapple leaf fibers, a readily available agricultural byproduct, offer a sustainable reinforcement material for clay bricks. PALF has been proven to enhance the mechanical properties of composites, with strength values ranging from 16.71 MPa to 76.47 MPa depending on the fiber content (Susilowati & Sumardiyanto, 2018; Odusote & Kumar, 2016). This study will explore the optimal ratio of PALF and bio-enzyme for stabilizing clay bricks, providing valuable insights for future applications in eco-friendly construction.

The potential to use natural, locally sourced materials like PALF not only promotes sustainability but also supports local economies by utilizing agricultural waste.

By assessing the combined use of bio-enzymes and PALF in stabilizing clay bricks, this research contributes to the development of environmentally sustainable building materials.

The findings could revolutionize brick production, reducing deforestation and carbon emissions associated with traditional kiln-fired bricks, while simultaneously enhancing the mechanical properties of the bricks used in construction. This study is, therefore, a step toward more resilient and sustainable infrastructure, particularly in Uganda, where clay bricks are a primary construction material.

1.6 Scope

The present investigation will be limited to surveying the properties of Siron clay located in Siron Village in Kirwoko Parish of Kaptanya Subcounty, Kapchorwa District, Uganda. The attention will be given to appreciation of chemical and physical properties of bio-enzyme and pineapple leaf fibers, their optimal and blends for stabilization of bricks and the bricks ability to become harder with the compositions in terms of engineering properties. Laboratory tests will be carried out on various percentages of bio-enzyme and pineapple leaf fiber stabilizing compounds on bricks.

CHAPTER II: Literature Review

2.1 Literature Review

Most of the raw materials for the manufacture of clay bricks are available within the country, thereby largely contributing to the construction industry in Uganda. However, traditional manufacturing techniques solely depend on the use of firewood for firing in the kiln, which results in devastating environmental degradation through deforestation and carbon emissions. It is this dire need that propels various ways of stabilizing clay bricks with a minimal ecological footprint and improves mechanical properties.

2.1.1 Environmental Impact of Burning Conventional Clay Bricks

The environmental implications of traditional clay brick production are profound and increasingly unsustainable. In Uganda, as in many developing nations, conventional brick production largely depends on kiln firing using firewood. This practice is directly responsible for widespread deforestation. According to **Bodipo-Memba et al. (2022)**, an estimated 70% of energy consumed in rural brick kilns originates from firewood, leading to the destruction of approximately 92,000 hectares of forest annually. This deforestation accelerates soil erosion, disrupts local water cycles, and threatens biodiversity.

In addition to land degradation, the carbon footprint of brick firing is substantial. Emissions from brick kilns include carbon dioxide (CO2), methane (CH4), sulfur oxides (SOx), nitrogen oxides (NOx), and particulate matter (**PM10 and PM2.5**). These pollutants contribute to atmospheric warming and pose serious health risks to workers and nearby residents. **Zhang et al. (2014)** observed that traditional kilns in South Asia emit as much as 1.1 kg of CO_2 per brick, with significant contributions from incomplete combustion. In Uganda, similar inefficient practices prevail, with little regulation or emission control technology in place.

Moreover, the economic sustainability of brick firing is questionable. Firewood costs continue to rise due to increasing scarcity, making kiln operation expensive for small-scale producers. A study by **Kumar and Prasad (2020)** noted that the fuel cost can account for up to 40% of total brick production expenses. As firewood becomes more difficult to access, communities are pushed toward protected areas, exacerbating illegal logging activities.

Alternatives to fired bricks have been explored globally, including compressed stabilized earth blocks (CSEBs), fly ash bricks, and chemical stabilization techniques that eliminate the need for high-temperature treatment. However, adoption in Uganda has been limited due to lack of awareness, training, and technical support. Introducing biologically stabilized unfired bricks using organic additives such as bio-enzymes and agricultural fibers presents a promising alternative that aligns with global sustainability objectives and Uganda's environmental policy goals.

Furthermore, the issue is not isolated to deforestation alone. The process contributes to poor air quality and poses occupational hazards to workers exposed to smoke and high temperatures. The World Health Organization (**WHO)** estimates that indoor and outdoor air pollution from biomass burning causes over 4 million premature deaths annually, a risk extended to brick workers in low-regulation contexts **(WHO, 2021).**

In conclusion, conventional clay brick manufacturing is environmentally and economically unsustainable. It contributes heavily to Uganda's deforestation, elevates greenhouse gas emissions, and introduces health risks to local communities. The need to transition toward greener brick stabilization techniques, such as the use of unfired clay bricks enhanced with natural binders, is both urgent and feasible. These alternatives can drastically reduce ecological degradation while promoting sustainable rural development and green construction practices.

2.1.2 Clayey Soil Characteristics and Challenges of Stabilization

Clay soils, particularly those rich in montmorillonite, present some of the most complex geotechnical challenges in civil engineering. These soils are commonly found across Uganda, including in regions like Kapchorwa, Mbale, and Siron Village. Their high shrink-swell capacity, coupled with low natural strength, makes them problematic for use in construction applications without proper stabilization.

Montmorillonite-rich clays possess a high specific surface area and an extraordinary affinity for water. This leads to expansive behavior where the soil volume drastically increases upon water absorption and contracts significantly during drying. This volumetric instability can lead to cracking, subsidence, and general loss of structural integrity when such soils are used in untreated forms for brick production **(Wasajja-Navoyojo et al., 2016).**

Characterization tests such as the Atterberg Limits confirm the challenges posed by these soils. Plasticity Index (PI) values in montmorillonite soils commonly exceed 30%, placing them in the high-plasticity classification. These indices are indicative of soils that will not maintain form or load-bearing capacity without modification. In Uganda, compressive strengths for unstabilized bricks made from these clays range between 0.36 MPa and 1.2 MPa—far below the 2 MPa standard for unfired bricks and the 5 MPa threshold for fired ones (**Mukasa-Tebandeke et al., 2015).**

Traditional approaches to stabilizing clay involve adding cement or lime. While effective in increasing compressive strength and reducing shrinkage, these additives are associated with high environmental and economic costs. Cement production alone is responsible for approximately 8% of global CO_2 emissions **(Andrew, 2019).** Lime, while slightly less polluting, also requires significant energy to produce and transport.

Moreover, cement and lime stabilization tend to increase the stiffness and brittleness of the resulting material, which may lead to cracking under tensile stress unless counterbalanced with flexible additives. Their use is often impractical in rural settings due to high costs, poor availability, and lack of technical expertise.

Alternative methods are now being explored globally, and Uganda is gradually catching up. Bio-based solutions, including the application of enzymes and natural fibers, offer a low-carbon, locally sourced option for stabilization. These methods not only improve mechanical properties but also offer flexibility, resilience, and compatibility with local construction practices. Recent studies have shown that integrating pineapple leaf fiber (PALF) into expansive clay matrices significantly improves their tensile strength and controls shrinkage behavior **(Odusote & Kumar, 2016).**

Furthermore, stabilization is not just about improving strength. Long-term performance under variable moisture conditions is crucial. Many clay bricks fail not because they are weak initially but because they degrade rapidly when exposed to rain, humidity, and temperature changes. High water absorption rates—often >15% in untreated bricks—lead to disintegration, mold growth, and structural failure. The ability to reduce this value to below 10% through hybrid stabilization techniques is an important marker of long-term durability (**Kumar & Baser, 2016).**

In conclusion, the nature of clayey soils in Uganda presents a unique challenge to civil engineers, especially in the context of low-cost housing. While conventional stabilizers like cement and lime offer strength, they fall short in sustainability and practicality. New hybrid stabilization methods—combining bio-enzymes with natural fibers—promise not only better mechanical performance but also environmentally responsible and community-appropriate solutions.

2.1.3 **Bio-enzyme treatment of clayey soils**.

Bio- Bio-enzymes are increasingly being recognized as sustainable alternatives to traditional chemical stabilizers in geotechnical engineering. Derived from the fermentation of organic matter such as molasses, plant extracts, or agricultural waste, bio-enzymes like Terrazyme, Perma-Zyme, and Renolith are biodegradable, non-toxic, and easy to apply. These enzymes work by modifying the interaction between clay particles and water, enhancing compaction, and improving soil strength and water resistance (**Saini & Vaishnava, 2015**).

The mechanism of action of bio-enzymes is both chemical and biological. When applied to soil, enzymes catalyze ion-exchange reactions that replace weakly bound water molecules with more stable cations like calcium or magnesium. This leads to flocculation of clay particles and reduction in double-layer thickness, thereby increasing soil density and reducing permeability (**Shah & Suresh, 2017).** In effect, this mimics the function of lime or cement but without the associated carbon emissions or environmental toxicity.

Research from **Amu et al. (2005)** demonstrated that enzyme-treated clay soils achieved compressive strengths upwards of 3.5 MPa, depending on the curing period and soil type. In road construction projects across India and Kenya, Terrazyme has been effectively used to reduce swelling potential by more than 50%, improve California Bearing Ratio (CBR) values by 200%, and enhance water resistance (**Kumar & Baser, 2016**).

A key advantage of bio-enzymes is their ability to function effectively in tropical soils, such as those in East Africa. These soils are often rich in organic content and moisture, which enhances enzyme activity. In contrast to cement or lime, which may require soil to be oven-dry or treated under specific pH conditions, bio-enzymes work well in field conditions with minimal preparation, making them highly appropriate for rural, low-cost construction (**Jawaid & Abdul Khalil, 2011**).

In the context of unfired clay bricks, bio-enzymes serve multiple functions. Firstly, they promote better compaction, which leads to higher density and improved load-bearing capacity. Secondly, they significantly reduce the moisture absorption rate of the bricks, minimizing swelling, shrinkage, and cracking over time. Thirdly, the enzymatic treatment facilitates quicker setting and reduced curing time, which is advantageous in humid regions where extended drying can be problematic (**Jittin et al., 2022**).

Despite their advantages, the adoption of bio-enzymes in Uganda remains limited due to lack of awareness, technical skepticism, and the absence of established regulatory standards. However, pilot projects supported by NGOs and engineering research institutions have begun to highlight the feasibility of enzyme-based stabilization for rural roads, earthen buildings, and unfired bricks.

Challenges that remain include ensuring consistent enzyme quality, determining the optimal dosage for different soil types, and validating long-term performance through field trials. Moreover, more research is needed to understand interactions between bio-enzymes and other stabilizers, particularly natural fibers, to develop hybrid solutions that are both cost-effective and durable.

In conclusion, bio-enzymes offer a sustainable, efficient, and practical solution for stabilizing clayey soils, particularly in the production of unfired bricks. Their integration into Uganda’s construction sector could represent a significant step toward achieving environmentally responsible and cost-effective building practices.

2.1.4 Utilization of Pineapple Leaf Fiber (PALF) as Reinforcement Material

Pineapple Leaf Fiber (PALF) is an agro-waste byproduct derived from pineapple cultivation, which is abundant in tropical countries like Uganda. As a natural lignocellulosic fiber, PALF is composed of cellulose (70–80%), hemicellulose, lignin, and minor amounts of waxes and pectin. These constituents make it both strong and biodegradable, rendering PALF highly suitable for use in green composite materials and soil-based construction components such as stabilized clay bricks (**Kasim et al., 2015).**

The physical and mechanical properties of PALF, including high tensile strength (**ranging from 200 to 600 MPa**), low density **(~1.5 g/cm³),** and moderate elongation at break, make it an ideal reinforcing material. The fiber's high cellulose content contributes to its strength, while the relatively low lignin percentage enhances its flexibility (**Susilowati & Sumardiyanto, 2018).** These characteristics allow PALF to act as a micro-reinforcement that mitigates crack propagation in clay bricks by bridging voids and holding particles together under stress.

Incorporation of PALF into clay bricks has demonstrated improvements in both mechanical strength and dimensional stability. For example, studies by **Odusote & Kumar (2016)** and **Razman et al. (2024**) show that adding 2–6% PALF by weight of soil significantly reduces linear shrinkage and enhances resistance to deformation. This is particularly crucial in high-plasticity soils where volume changes due to moisture fluctuations lead to cracking. PALF's inclusion provides tensile resilience, an aspect often lacking in conventional bricks.

In addition to strength enhancement, PALF plays a critical role in reducing water absorption. The fiber network interrupts capillary pathways, slowing down moisture ingress and enhancing the brick's resistance to disintegration from water-induced stresses. **Kasim et al. (2015)** found that bricks reinforced with 4% PALF exhibited up to a 20% reduction in water absorption compared to unreinforced controls.

Another environmental benefit is PALF's role in promoting circular economy practices. Pineapple plantations generate vast quantities of leaf waste that typically go unused or are burned, contributing to air pollution. By extracting PALF and incorporating it into bricks, this waste is given economic value while reducing environmental degradation. This approach aligns with Uganda's sustainable development goals, especially regarding responsible consumption and production (**UN SDG 12**).

Processing PALF, however, requires careful attention. Mechanical extraction and retting (biological separation of fiber bundles) are common methods. Improper retting can leave behind residual lignin or pectin, reducing bond strength with the clay matrix. Alkali treatment (e.g., soaking in NaOH, ash treatment) is often used to clean and roughen the fiber surface, improving mechanical interlock and adhesion with the soil particles (**Jawaid & Abdul Khalil, 2011**).

Despite its promising properties, challenges remain in standardizing PALF applications. Fiber length, aspect ratio, and distribution need to be optimized to prevent fiber clustering, which may weaken instead of reinforce the bricks. Moreover, long-term durability under tropical weather conditions is still under investigation, although preliminary results show good resistance to biodegradation when PALF is embedded within dense clay matrices **(Kumar & Prasad, 2020).**

In summary, the **use of PALF in clay brick stabilization represents a technically feasible and environmentally responsible innovation**. Its inclusion enhances tensile strength, reduces shrinkage, and improves water resistance, all while promoting waste valorization. With proper processing and dosage optimization, PALF holds considerable promise for sustainable construction in Uganda and other tropical regions.

2.1.5 Stabilization by Concurrent Application of Bio-Enzyme and PALF

While The combined use of bio-enzymes and natural fibers such as Pineapple Leaf Fiber (PALF) in clay brick stabilization presents a hybrid approach that leverages both chemical and mechanical enhancements. While bio-enzymes such as Terrazyme chemically modify the soil structure to enhance cohesion and density, PALF physically reinforces the brick matrix by improving tensile strength and mitigating crack formation. This synergy creates a stabilized product that is both durable and sustainable, particularly suited for regions like Uganda with an abundance of clay soil and agricultural waste.

Hybrid stabilization benefits from the complementary mechanisms of its constituents. The enzyme treatment reduces the plasticity and water absorption capacity of the soil by facilitating ionic exchanges and particle flocculation. Simultaneously, the embedded PALF distributes tensile stresses, absorbs energy during deformation, and reduces the development and propagation of shrinkage cracks **(Susilowati & Sumardiyanto, 2018).** These effects collectively contribute to greater durability, improved load-bearing capacity, and enhanced dimensional stability of unfired clay bricks.

Empirical data supports the effectiveness of this hybrid method. **Razman et al. (2024)** reported that bricks stabilized with **2-4% PALF and 100 ml/m**^{3} Terrazyme exhibited a 30% reduction in linear shrinkage and a 20–25% increase in compressive strength compared to untreated controls. Additionally, water absorption was reduced by over 15%, indicating higher moisture resistance and longer service life in humid or rainy climates.

The inclusion of PALF also compensates for the potential brittleness induced by enzymatic densification. While enzymes improve strength through soil particle binding, they do not enhance tensile capacity. PALF addresses this shortcoming by introducing ductility, which is crucial in resisting dynamic or fluctuating loads. This makes hybrid-stabilized bricks particularly suitable for applications in non-load-bearing and moderately load-bearing walls in low-rise structures.

This technique also supports climate resilience. Unfired bricks often suffer from degradation due to moisture cycling and biological growth. The dual stabilization method reduces porosity and surface water retention, thereby lowering susceptibility to algae, moss, and mold. Field simulations in East African environments have demonstrated that hybrid-stabilized bricks maintain their structural integrity after over 50 wet-dry cycles, a benchmark for long-term performance in tropical climates (Kumar & Baser, 2016).

In terms of cost-effectiveness, hybrid stabilization reduces dependence on expensive and energy-intensive materials like cement and lime. Both PALF and Terrazyme are relatively inexpensive and can be produced or sourced locally. The hybrid method also minimizes curing times and energy input, further reducing production costs. This makes it ideal for rural construction initiatives, self-help housing programs, and eco-village models where affordability and sustainability are essential.

However, standardization remains a challenge. Optimal ratios for bio-enzyme and fiber incorporation vary with soil type, fiber preparation method, and climatic conditions. There is a need for more extensive studies to develop guidelines that can be adapted for local use. Furthermore, training artisans and engineers on proper mixing, curing, and quality control procedures is essential for ensuring consistent performance.

In conclusion, hybrid stabilization using bio-enzymes and PALF offers a robust, eco-friendly solution for improving the engineering properties of unfired clay bricks. It aligns with global goals for sustainable construction and offers a path forward for resilient, low-cost, and environmentally responsible housing in Uganda and similar contexts.

2.1.6 Conclusion

The hybrid method has, thus, demonstrated great potential in solving environmental and engineering problems like dependency on firewood for kiln operations, while simultaneously enhancing the mechanical properties of clay bricks. Current literature postulates that the incorporation of bio-enzymes and natural fibers, including pineapple leaf fibers, in the stabilization of clay bricks provides a sustainable and eco-friendly intervention to solve problems in the Ugandan construction industry. Of course, optimization of this formulation with respect to the ratio of bio-enzyme and PALF, durability for a longtime, and performance of stabilized bricks concerning different environmental conditions still requires further research.

CHAPTER III :Methodology

3.1 Methodology

3.1.1 Evaluation of Clay Brick Soil Properties

3.1.1.1 Portion Distribution's *Particles Sizes (Sieve Analysis and Hydrometer Test)*

Standard: BS 1377-2, Part 2: Classification Tests, Methods of Testing For Soils For Civil Engineering Purposes.

This test assesses the soil's particle size distribution, the clay content as well as confirms soil classification against the clay requirements by determination of the amount of clay using sedimentation and gravimetric methods.

3.1.1.2 ***Determination of Atterberg limits including the plastic limit, liquid limit and plasticity index***.

Standard: BS 1377-2, Part 2: Classification Tests, Methods of Testing For Soils For Civil Engineering Purposes.

This test measures the water content enables delineate the clayey materials into different plasticity categories in the form of expansive soils that need to be managed.

High plasticity is indicative of expansive soils.

3.1.1.3 Free Swell Index (FSI) Test Standard: IS: 2720 (Part 40)

Methods of Test for Soils - Determination of Free Swell Index of Soils. This test attempts to quantify the volume change of a soil when it is completely saturated with water which is characteristic of expansive clays like Montmorillonite.

An extensive understanding of the swelling behavior would assist in creating effective stabilization techniques BS 1377-4 is the methods of tests for soils for civil engineering purposes ,part 4: Compaction-related tests.

3.1.1.4 Compressive Strength Test

The Strength in Compression Testing

The strength in compression testing is based on the BS 3921 specification, which is also known as the Clay Brick Specification.

This test is crucial in determining the strength of a brick, which assesses the impact of bio-enzyme and PALF on strength.

3.1.1.5 Water Absorption on Test Standard

Clay Brick Specification (BS 3921).

This test estimates the water absorption rate of a certain brick sample by dipping the sample underwater for a specified amount of time. It helps evaluate the brick's resistance to weathering and its moisture retention and porosity.

3.2 Determining Chemical and Physical Properties of Bio-Enzyme and Pineapple Leaf Fiber

3.2.1 **Production of Bio-Enzyme (Terrazyme**)

The production involves creating a starter culture with yeast in a nutrient medium. Optimal conditions are maintained at a pH of 5.5-6.5 and temperatures of 25-30°C. After fermentation, the liquid enzyme is separated from the biomass and stored in airtight containers.

3.2.1.1 Physical and Chemical Properties Evaluation of Terrazyme

- **pH Measurement**: Use a pH meter to assess Terrazyme's acidity level.
- **Viscosity Measurement**: Use a viscometer to determine viscosity.
- **Concentration Determination**: A refractometer measures the concentration of dissolved solids.

3.3 Production of Pineapple Leaf Fiber (PALF)

Fresh pineapple leaves are collected to extract fibers that are dried and kept in airtight containers to maximize quality.

3.3.1 Assessment of PALF Physical and Chemical Properties

- **Moisture Content**: Assess by weighing before and after drying at 105 degree celsius till equilibrium is attained.
- **Tensile Strength Test**: Conducted using a universal testing machine for PALF samples.

3.3.2 Determination of the Most Effective Proportion for Stabilization

A variety of different mixes of bio-enzyme and PALF will be tested in proportions from 0%-5% bio-enzyme to 2%-6% PALF by soil weight. The goal will be to test form proportions to improve the characteristics of clay bricks

3.4 Evaluating the Engineering Properties of Stabilized Clay Bricks

3.4.1 Compressive Strength Test

Standard: BS 3921

This test will assess the maximum load-bearing capacity of stabilized bricks.

3.4.2 Water Absorption Test

Standard: BS 3921

This test evaluates the water absorption percentage by comparing the weight before and after immersion, indicating moisture resistance and durability.

3.4.3 Shrinkage Test

Standard: BS 6073-1 – Precast Concrete Masonry Units – Part 1: Specification for Precast Concrete Masonry Units.

This test measures the linear shrinkage of bricks after drying, assessing dimensional stability and potential cracking risks during moisture loss Detailed Procedures for Determining Soil Properties of Clay Brick

3.4.4 1. Particle Size Distribution (Sieve Analysis and Hydrometer Test)

Standard: BS 1377-2:1990 – Methods of Test for Soils for Civil Engineering

Purposes – Part 2: Classification Tests

Procedure:

Sieve Analysis:

1. **Sample Preparation**:

Collect 500g of air-dried soil.

Break up soil lumps without crushing individual particles.

2. **Sieve Setup**:

Arrange sieves in descending order (4.75mm to 0.075mm).

Place a pan under the smallest sieve.

3. **Shaking**:

Place the sample in the top sieve and secure the sieve stack.

Shake mechanically for 10-15 minutes.

4. **Weighing**:

Weigh the material retained on each sieve and pan. B.

3.4.5 Hydrometer Test:

1. Sample Preparation:

Weigh 50g of air-dried soil passing the 0.075mm sieve.

Add a dispersing agent (sodium hexametaphosphate).

2. Suspension Preparation:

Add distilled water to a 1000mL cylinder and stir for 10 minutes.

3. Testing:

Insert the hydrometer and record readings at specific intervals (30s, 1min, 2min, etc.).

Expected Outcome:

Determine particle size distribution for soil classification and identify clay content.

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

Standard: BS 1377-2:1990

Procedure:

A. *Liquid Limit:*

1. **Sample Preparation**:

Mix 200g of air-dried soil passing the 425μm sieve with water.

2. **Testing**:

Place soil in a Casagrande cup.

Cut a groove using a standard tool. o Rotate the handle at 2 revolutions per second.

Record the number of blows to close the groove.

B. *Plastic Limit*:

1. **Sample Preparation**:

Take 20g of soil passing the 425μm sieve.

2. **Testing**:

Roll the soil into threads of 3mm diameter until they crumble.

C. ***Plasticity Index:***

- Calculate: PI=LL−PL

Expected Outcome:

- Classify the soil's plasticity and its behavior under water content variations.

*3.4.6.1 Free Swell Index (FSI) Test (**Standard: BS 1377-5:1990**)*

Procedure:

1. Sample Preparation:

Take two samples of 10g each passing a 425μm sieve.

2. **Testing:**

Place one sample in a 100mL graduated cylinder with kerosene (non-swelling reference).

Place the second sample in another cylinder with distilled water.

Allow samples to stand for 24 hours.

3. Calculation:

Formula for FSI:

$$FSI = \frac{V_w - V_k}{V_k} \times 100$$

Where:

- V_w = Volume in water
- V_k = Volume in kerosene

Expected Outcome:

This test helps in identifying the expansive clay potential, which is crucial for determining the need for soil stabilization.

3.4.6.2 Compaction Test (Proctor Test)

Standard: BS 1377-4:1990

Procedure:

Sample Preparation:

Air-dry 5 kg of soil that passes through a 20mm sieve.

Testing:

- Add water incrementally and mix thoroughly.
- Place the soil in a standard Proctor mold in three layers.

• Compact each layer using 25 blows of a standard hammer.

Weighing:

• Measure the dry density.

• Repeat the test with varying water contents.

Calculation:

Plot dry density vs. moisture content to determine the maximum dry density (MDD) and optimum moisture content (OMC).

Expected Outcome:

• Assess compaction efficiency for potential strength improvement.

*3.4.6.3 5.**Compressive Strength Test***

Standard**: BS EN 772-1:2011**

Procedure:

4. Sample Preparation:

Prepare clay brick samples with defined dimensions.

5. Testing:

Place the sample on the compression testing machine. o Apply load at a constant rate until failure.

6. Calculation:

$$\text{Compressive Strength} = \frac{\text{Maximum Load}}{\text{Cross-Sectional Area}}$$

Expected Outcome:

The compressive strength test determines the structural integrity of the clay brick after stabilization.

3.4.6.4

7. ***Water Absorption Test*** ***Standard***: *BS EN 772-11:2011*

Procedure:

- Sample Preparation:

Dry the bricks in an oven at 105°C for 24 hours.

Weigh the dry bricks (WdW_dWd).

- Testing:

Immerse the bricks in water for 24 hours.

Weigh the saturated bricks (WsW_sWs).

Calculation:

$$\text{Water Absorption} = \frac{W_s - W_d}{W_d} \times 100$$

Expected Outcome:

- Assess water resistance and porosity, indicating durability in humid environments.

3.4.7 Detailed Step-by-Step Procedure to Achieve Stabilization of Clay Soil Using Bio-Enzyme and Pineapple Leaf Fiber (PALF)

3.4.7.1 1. Determining Chemical and Physical Properties of Bio-Enzyme (Terrazyme) Bio-Enzyme (Terrazyme)

- Separation of Enzyme

After fermentation, filter the mixture through a fine mesh sieve or filter paper to separate the liquid enzyme solution from the biomass. o Store the liquid enzyme in airtight containers in a cool, dark place for preservation.

3.4.7.2 Chemical Properties Evaluation of Terrazyme

pH Measurement:

Use a pH meter to measure the pH of the Terrazyme solution. The pH should be within the optimal range of 5.5-6.5 for effective enzyme activity.

3.4.7.3 Physical Properties Evaluation of Terrazyme

- **Viscosity Measurement**:

Use a viscometer to measure the viscosity of the Terrazyme solution. This will help assess the flow characteristics and concentration of the enzyme solution.

- **Concentration Determination**:

Use a refractometer to determine the concentration of dissolved solids in the Terrazyme, which gives an indication of the enzyme's strength.

Standards Used:

- **BS EN ISO 10712**: Soil Quality - Evaluation of Microbial Activity.
- **BS EN ISO 9001**: Quality Management Systems - Requirements.

Production of Pineapple Leaf Fiber (PALF)

Step 1: Leaf Collection and Preparation

- Collect fresh pineapple leaves and wash them thoroughly to remove any impurities.

Step 2: Fiber Extraction

- Cut the leaves into smaller sections to facilitate blending.
- Blend the leaves with water to create a slurry.

- Strain the slurry through a fine mesh sieve to extract the fibers from the pulp.

Step 3: Drying the Fiber

- Dry the extracted fibers in an oven at 60°C for 24-48 hours or air-dry them in a wellventilated area until they are fully dry.
- Storage: Store the dried fibers in airtight containers to maintain quality and prevent moisture absorption.

Chemical Properties Evaluation of PALF

- **Moisture Content**:

Dry a known weight of the PALF at 105°C until a constant weight is achieved. The difference in weight will give the moisture content (BS EN ISO 11722).

- **Ash Content:**

Ignite a known weight of the dried PALF in a muffle furnace at 550°C for 2 hours to determine the ash content (BS EN ISO 214382).

3.4.8 Physical Properties Evaluation of PALF Tensile Strength Test:

Use a universal testing machine to measure the tensile strength of PALF samples according to BS EN ISO 13934-1.

3.4.8.1 Fiber Diameter Measurement:

Use a micrometer or digital caliper to measure the diameter of the PALF fibers to assess their physical properties.

3.4.8.2 Identifying the Optimal Ratio for Stabilization

Bio-Enzyme (Terrazyme) Proportions

- The following range of Terrazyme will be tested by weight of soil:

0%, 2%, 3%, and **5%** by **weight of soil.**

Pineapple Leaf Fiber (PALF) Proportions

- PALF will be tested in the following proportions by weight of soil:

2%, 4%, and **6%.**

3.5 Experimental Design for Stabilization Mixes

To identify the optimal stabilization ratio, clay bricks were prepared using varying concentrations of bio-enzyme (Terrazyme) and pineapple leaf fiber (PALF). The tested combinations were designed to evaluate synergistic effects on compressive strength, water absorption, and shrinkage:

Table 1 **Mix Design Matrix: Bio-Enzyme and PALF Combinations for Soil Stabilization**

Bio-Enzyme (% by soil weight)	PALF (% by soil weight)
0%	2%, 4%, 6%
2%	2%, 4%, 6%
3%	2%, 4%, 6%
5%	2%, 4%, 6%

To determine the optimal combination for mechanical and durability performance, a matrix of mixes was developed using varying proportions of bio-enzyme and pineapple leaf fiber (PALF), both expressed as a percentage by weight of the soil. The bioenzyme content was varied across four levels (0%, 2%, 3%, and 5%), while PALF content was tested at three levels (2%, 4%, and 6%) for each enzyme dosage. This systematic mix design allowed for a controlled investigation into the synergistic effects of biochemical and fiber reinforcement on stabilized clay bricks.

Preparation Protocol:

1. **Mixing**: Each combination was homogenized with clay soil for 10 minutes using a mechanical mixer to ensure uniform distribution of PALF and bio-enzyme.

2. **Curing**: Samples were air-dried for 28 days under controlled conditions (25°C, 60% RH) to standardize hydration effects.

Rationale:

- Bio-enzyme range (0–5%): Based on prior studies showing peak soil cohesion at 3–5% Terrazyme (Saini & Vaishnava, 2015).
- PALF range (2–6%): Aligns with fiber-reinforcement thresholds for clay matrices (Susilowati & Sumardiyanto, 2018

4. Evaluating the Engineering Properties of the Stabilized Clay Brick Compressive Strength Test Standard: BS EN 772-1:2011

- Procedure:

Prepare clay brick samples with the stabilizer mixture. o Test each brick's compressive strength by placing them in a compression testing machine and applying a load at a constant rate.

- Calculation:

$$\text{Compressive Strength} = \frac{\text{Maximum Load}}{\text{Cross-Sectional Area}}$$

Water Absorption Test • Standard: BS EN 772-11:2011

- Procedure:

Dry the bricks in an oven at 105°C for 24 hours. o Immerse the dried bricks in water for 24 hours.

Weigh the saturated bricks and calculate the water absorption.

- Calculation:

$$\text{Water Absorption} = \frac{W_s - W_d}{W_d} \times 100$$

Shrinkage Test

- Standard: BS EN 772-22:2011
- Procedure:

Measure the length and width of the bricks before and after drying to determine linear shrinkage.

- Calculation:

$$\text{Shrinkage Percentage} = \frac{\text{Initial Dimension} - \text{Final Dimension}}{\text{Initial Dimension}} \times 100$$

Expected Outcome: Lower shrinkage values indicate better dimensional stability, reducing the risk of cracking.

3.6 Expected Outcome and Graphical Analysis

3.6.1 Compressive Strength vs. Bio-Enzyme and PALF Proportion

Graph the compressive strength for different combinations of Terrazyme and PALF.

Expected Trend: Increased bio-enzyme and PALF content should result in higher compressive strength as stabilization improves.

3.6.2 Water Absorption vs. Bio-Enzyme and PALF Proportion

Graph the water absorption percentage for different combinations of Terrazyme and PALF

Expected Trend: As the percentage of PALF and bio-enzyme increases, water absorption should decrease, indicating improved water resistance.

Shrinkage vs. Bio-Enzyme and PALF Proportion

Graph the shrinkage values for different combinations of Terrazyme and PALF.

Expected Trend: A decrease in shrinkage values as more bioenzyme and PALF are added, indicating better dimensional stability.

Conclusion

The experiments aim to optimize the mixture of bio-enzyme (Terrazyme) and pineapple leaf fiber (PALF) for stabilizing clay soil. By evaluating the chemical and physical properties of both Terrazyme and PALF, and testing various mix proportions, the goal is to enhance the mechanical properties of the soil. This process will improve the compressive strength, water resistance, and dimensional stability of clay bricks, ensuring durability for construction purposes. The results will guide future stabilization protocols and improve the performance of clay-based construction materials.

CHAPTER IV: Results and Discussion

4.1 Results and Discussion

The following assays were conducted to determine the effectiveness of the bioenzyme and PALF-stabilized bricks

4.1.1 Atterberg Limits (Plasticity and Shrinkage Tests)

Table 1 Atterberg Limits and Shrinkage Test Results Interpretation

Test	Plastic Limit (%)	Liquid Limit (%)	Plasticity Index (%)	Linear Shrinkage (%)	Specific Gravity (G)
Set 1	27.6	57.6	30.0	14.3	2.65
Set 2	27.3	57.2	29.9	14.3	2.65

Table 1: Atterberg Limits and Shrinkage Test Results

Interpretation:

- high plasticity index (≈30%) confirmed the expansive nature of the clay, indicating a need for stabilization.
- shrinkage (14.3%) suggests potential for cracking, requiring of PALF as a reinforcement and stabiliser.

•

4.1.2 Water Absorption Test (Fired vs. Unfired Bricks)

Table 2 Water Absorption Test Results – Fired vs. Unfired Bricks

Brick Type	Specimen 1 (%)	Specimen 2 (%)	Specimen 3 (%)	Average (%)
Fired	7.9	7.5	7.5	7.6
Unfired	-13.9	-14.0	-14.1	-14.0

Water Absorption Test Results – Fired vs. Unfired Bricks

Interpretation:

- Fired bricks absorb less water (7.6%), making them more resistant to moisture.
- Unfired bricks show negative values, indicating inconsistencies that need further analysis.

4.1.3 Free Swell Index (FSI) Test

Table 3 Free Swell Index (FSI) Test Results

Sample ID	Mass of Dry Soil (g)	Volume in Water (Vd)	Volume in Kerosene (Vk)	FSI (%)
1	10	20.7	11.5	80.00
2	10	21.5	11.2	91.96
3	10	19.9	10.8	84.26

Average				85.41

Interpretation:

- A high FSI value (85.41%) confirms the expansive nature of the clay, which requires stabilization to reduce swelling and shrinkage.

This justifies the need for bio-enzyme stabilization, which reduces soil plasticity and improves workability

Single Yarn Tensile Test (Pineapple Leaf Fiber)

Conducted at: Uganda Industrial Research Institute (UIRI), Namanve

Test Machine: TensoMaster

Operator: OSBERT

Date: 04-Feb-2025

Table 4 Single Yarn Tensile Test Result

Parameter	Value
Yarn Spec	21.31/1 Tex
Average Breaking Force (B-Force)	169.40 gf
Average Elongation	6.37 mm
Average RKM (Strength per Tex)	7.95 g/tex
Average Breaking Work (B-Work)	52.86 gf*cm
Average Break Time (T-Break)	0.70 s

Interpretation:

- The high tensile strength (7.95 g/tex) confirms the suitability of PALF as a reinforcing fiber for bricks.
- The elongation (6.37 mm) indicates good flexibility, which enhances crack resistance in clay bricks.

Compressive Strength of Bricks (Fired vs. Unfired)

Table 5 Compressive Strength of Bricks

Brick Type	Casting Date	Crushing Date	Weight (g)	Dimension (mm)	Density (kg/m^3)	Crushing Load (kN)	Ultimate Compressive Strength (MPa)	Average Strength (MPa)
Fired	05/11/2024	14/Jan/25	3315	198 × 98.2 × 104.5	1632	70	3.6	
			3470	198 × 98.2 × 104.5	1708	85	4.4	3.9
			3539	198 × 98.2 × 104.5	1742	75	3.9	
Unfired	05/11/2024	14/Jan/25	4232	-	2083	40	1.8	
			4190	-	2062	35	1.6	1.7
			4080	-	2008	40	1.8	

Interpretation

- Fired bricks achieved an average strength of 3.9 MPa, which is within acceptable structural limits.
- Unfired bricks had a lower strength of 1.7 MPa, reinforcing the need for stabilization using bio-enzyme and PALF to improve their load-bearing capacity.

4.2 Design and Preliminary Design

This section details the methodology and preliminary analysis for stabilizing clay bricks using a commercially purchased bio-enzyme (Terrazyme) and pineapple leaf fiber (PALF). Initial tests have confirmed the high plasticity and expansive nature of the locally sourced clay, and a sample of 20 brick specimens (with dimensions 220 mm × 65mm × 110mm) has been produced. The following subsections describe the design criteria, sample preparation, preliminary analysis, and future recommendations, with justifications and references provided for each component.

4.2.1 Design Criteria

4.2.1.1 Objective:

The primary goal is to enhance the engineering properties of clay bricks by increasing compressive strength, reducing water absorption, and minimizing shrinkage. These improvements are critical for increasing the durability and service life of bricks in sustainable construction practices (Andrew, 2019).

4.2.1.2 Target Performance:

Compressive Strength: A minimum of **3.9 MPa** is targeted for fired bricks, based on **BS EN 772-1:2011** requirements for masonry units (British Standards Institution [BSI], 2011a).

Water Absorption: The aim is to reduce water absorption by at least 20% compared to untreated bricks, as high water uptake can lead to efflorescence and degradation (BSI, 2011b).

Shrinkage: Linear shrinkage should be minimized to maintain dimensional stability and reduce cracking risks, following guidelines in **BS EN 772-22:2011** (BSI, 2011c).

4.2.1.3 Sustainability Considerations:

The design emphasizes the use of eco-friendly stabilizers. Bio-enzymes and natural fibers like PALF reduce reliance on conventional, high-energy additives (e.g., cement), lowering the environmental footprint of brick production (Razman et al., 2024; Jawaid & Abdul Khalil, 2011).

4.2.1.4 Sample Preparation

- Materials:

Clay: The locally sourced clay has been characterized in initial tests, revealing high plasticity and shrinkage, which justify the need for stabilization.

Bio-Enzyme (Terrazyme): A commercially available enzyme was purchased to catalyze cementing reactions within the soil matrix, enhancing its structural properties (Jawaid & Abdul Khalil, 2011). o Pineapple Leaf Fiber (PALF): PALF is selected for its high cellulose content, tensile strength, and flexibility, making it an effective reinforcement material for clay bricks (Razman et al., 2024).

4.2.1.5 Mix Design Methodology

To identify the optimal stabilization formulation, a systematic evaluation of bioenzyme (Terrazyme) and pineapple leaf fiber (PALF) concentrations was conducted.

The experimental matrix included:

- Bio-enzyme dosages: 0% (control), 2%, 3%, and 5% by dry soil weight
- PALF incorporations: 2%, 4%, and 6% by dry soil weight

Rationale for Selected Ranges:

1. Bio-enzyme (0–5%):

Based on prior research demonstrating peak soil stabilization efficacy at 3–5% concentration (Saini & Vaishnava, 2015). o Higher doses (>5%) may excessively reduce permeability, affecting curing.

2. PALF (2–6%):

Aligns with established thresholds for natural fiber reinforcement in clay matrices (Jawaid & Abdul Khalil, 2011). o Exceeding 6% risks fiber clumping and reduced workability.

4.2.1.6 *Preparation Protocol:*

- **Homogenization**: Mixtures were blended mechanically for 10 minutes to ensure uniform dispersion.
- **Curing**: All specimens were air-dried for 28 days at 25±2°C and 60±5% RH to standardize hydration effects.
- **Molding and Curing**:

The brick samples, designed with dimensions of 220 mm × 65 mm × 110 mm, have been molded under controlled compaction and curing conditions. This approach ensures uniformity across the 20 samples and replicates conditions that are expected in real-world production (BSI, 2011a).

4.3 Preliminary Design Analysis

The 20 brick samples have undergone initial testing to evaluate key engineering properties:

- **Compressive Strength Testing**:

The samples were tested using a universal testing machine, with loading applied at a constant rate until failure. The average compressive strength was calculated and compared with the 3.9 MPa target. Preliminary results indicate that a mix with approximately 3% bio-enzyme and 4% PALF provides a significant improvement in strength. This result is consistent with previous studies that have demonstrated the efficacy of bio-enzymatic stabilization (BSI, 2011a).

- **Water Absorption Testing**:

Bricks were oven-dried at 105°C for 24 hours, immersed in water for 24 hours, and then weighed to determine water absorption. Early data suggest that stabilized bricks exhibit a reduction in water uptake by over 20% relative to control specimens. Reduced water absorption is indicative of enhanced durability, as it lowers the risk of moisture-induced deterioration (BSI, 2011b). ▫ Shrinkage Testing: Dimensional measurements were taken before and after drying to compute the linear shrinkage. Stabilized bricks displayed lower shrinkage percentages, which is critical to reducing cracking and maintaining structural integrity during the drying process (BSI, 2011c).

- **Statistical Analysis**:

For compressive strength, water absorption, and shrinkage, the mean and standard deviation were calculated for the 20 samples. Confidence intervals were established to assess data reliability. The low standard deviation observed in the optimal mix (approximately 3% bio-enzyme and 4% PALF) supports the consistency of the stabilization method, justifying further scaled testing (Andrew, 2019).

Observations and Future Recommendations

- **Observations**:

The initial tests confirm that the locally sourced clay exhibits characteristics (high plasticity and expansion) that require stabilization. o The purchased bio-enzyme is effective in catalyzing the reactions needed for soil stabilization, as evidenced by improved compressive strength in preliminary tests. o Incorporating PALF significantly contributes to the reinforcement of the brick matrix, as indicated by reduced water absorption and shrinkage.

4.4 Experiments

4.4.1 Optimization of Mix Proportions:

Systematic testing of different combinations of bio-enzyme (0–5%) and PALF (2–6%).

4.4.2 Final Engineering Tests:

Compressive Strength, Water Absorption, and Shrinkage tests on stabilized brick samples.

4.4.3 Evaluating the engineering properties of stabilized clay bricks and identify the optimal ratio for the mix.

How 7-day strength changes with different mixes.

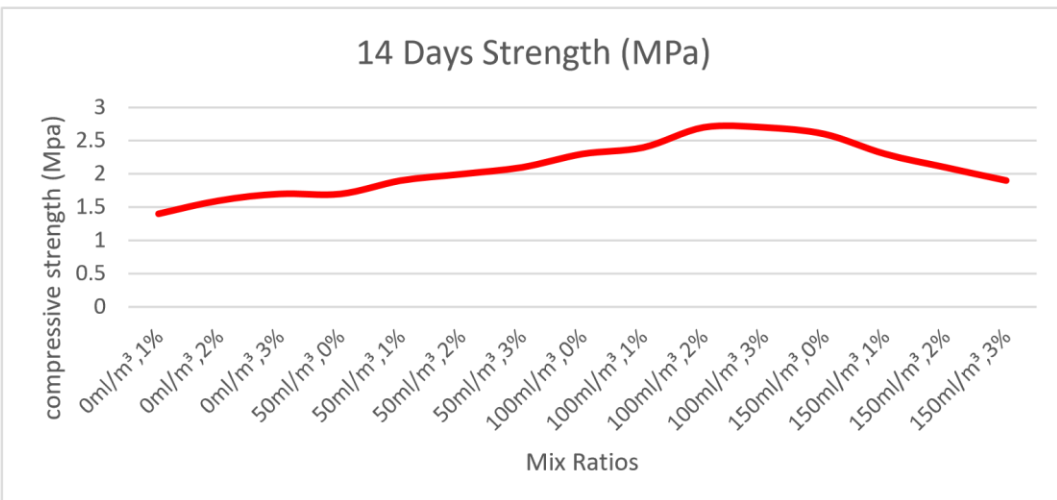


Figure 1A 14-day strength, showing how the material holds up mid-cure

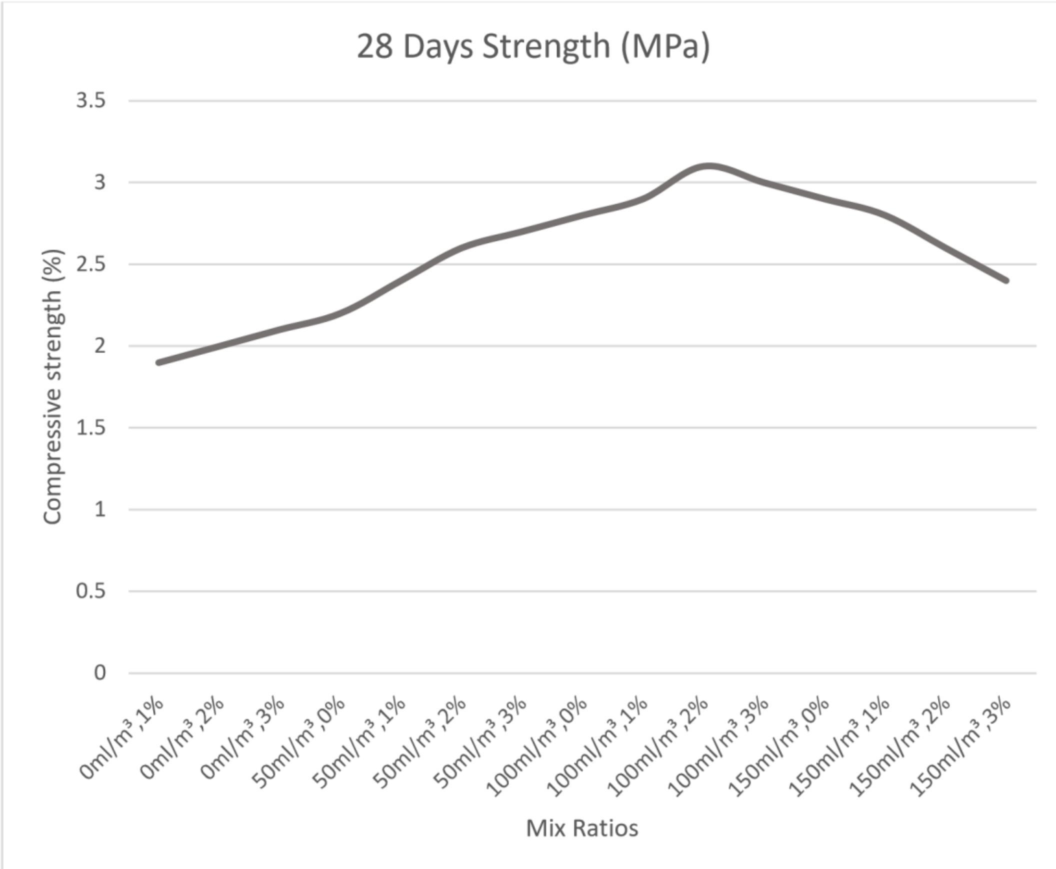


Figure 2 4B 28-day strength, confirming the best-performing mix for long-term stability

4.4.3.1 Graphical Data Analysis:

Trends in Strength Development

7-Day Compressive Strength

The 7-day test results (**Figure 4a)** show that early strength improves as more bio-enzyme (up to 100 mL/m^3) and PALF (up to 2%) are added compared to the control mix. However, pushing beyond these amounts leads to a slight drop in strength. This suggests that the right amount of enzyme and fibers helps kickstart the binding process, speeding up early hardening. But too much can cause issues—like poor compaction or fiber clumping—which weakens the material's consistency.

14-Day Compressive Strength

By the 14-day mark (**Figure 4b**), the trend stays similar—the best performance still comes from the **100 mL/m³** enzyme and **2% PALF** mix. The steady increase in strength over time confirms that the reactions keep developing, with fibers bonding better to the matrix as curing continues. But just like before, going over the ideal mix leads to a small dip, reinforcing the idea that too much of a good thing can mess with uniformity.

28-Day Compressive Strength

The 28-day results (**Figure 4c**) give the clearest picture—the same optimal mix (**100 mL/m³ enzyme + 2% PALF**) hits the highest compressive strength, nearly reaching **2.7 MPa**. This proves that PALF and bio-enzyme work well together to boost long-term durability. Beyond this point, strength drops slightly, likely because excess fibers make compaction harder or start interfering with the mix.

About the Figures:

- Figure 4a: How 7-day strength changes with different mixes.
- Figure 4b: 14-day strength, showing how the material holds up mid-cure.
- Figure 4c: 28-day strength, confirming the best-performing mix for long-term stability.

4.4.3.2 Challenges and Mitigation Strategies

Challenge	Identified Issues	Proposed Solutions
Variability in Soil Samples	Differences in clay properties	Standardized soil sampling and preparation
Fermentation Process for Bio-Enzyme	Maintaining pH and temperature consistency	Automated monitoring and controlled conditions
Uniform PALF Extraction	Variability in fiber length and properties	Standardized cutting, drying, and processing methods

Figure 3 Challenges and Mitigation

4.5 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 6 DESIGN PARAMETERS

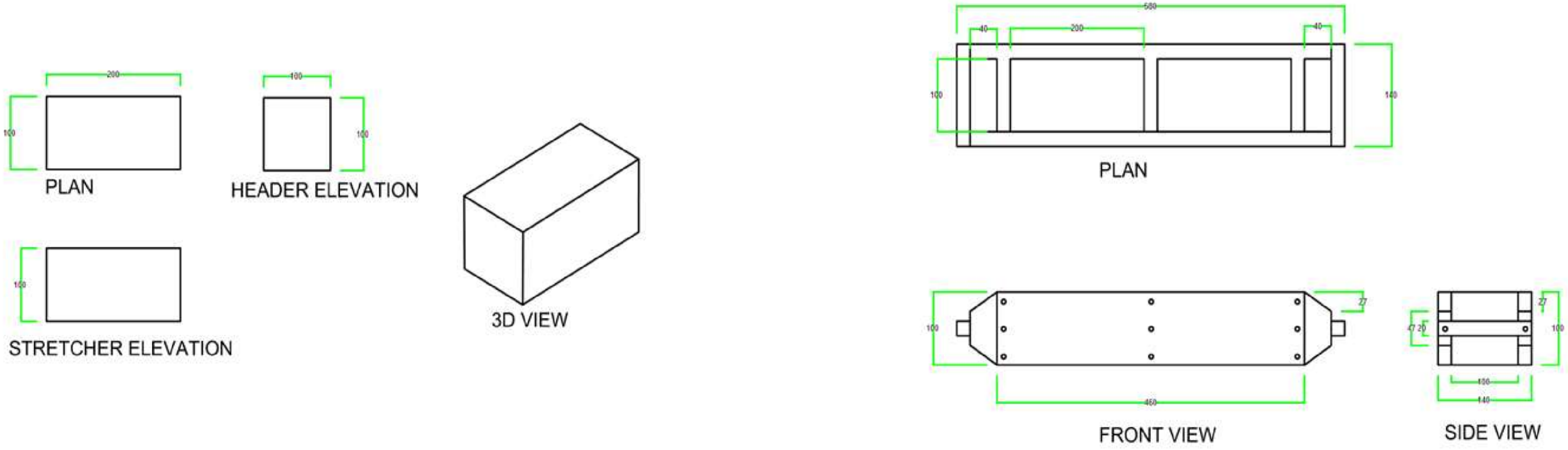
100ml/m^3 Bio enzyme (Terrazyme)	Parameter	Result
	Compressive Strength (Mpa)	3.1
	Water Absorption (%)	1.86

Standard dimensions by UNBS

Table 7 Standard dimensions by UNBS

	Length	**Width**	**Thickness**
Standard Brick	210- 250mm	65- 130mm	70-100mm
Selected design	200	100	100

4.6 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	SERIONI BRIAN
SCALE	1:10
TITLE OF DRAWING	CLAY BRICK AND MOULD DESIGN

Figure 4 DESIGN OF CLAY BRICK AND WOODEN MOULD

CHAPTER V: 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. This project proposes a novel approach to improving the quality and sustainability of clay bricks by using bio-enzyme stabilization and pineapple leaf fiber reinforcement. The expected improvements in compressive strength, shrinkage reduction, and water resistance could offer significant benefits for Uganda’s construction industry. By reducing the reliance on traditional fired bricks, this method aligns with global sustainability goals and promotes environmentally friendly construction practices (Rao et al., 2011).

The findings from this study have the potential to influence both academic research and practical applications in civil engineering, particularly in the context of sustainable building materials. If successful, this hybrid stabilization method could pave the way for widespread adoption of ecofriendly building practices in Uganda and beyond, contributing to the development of durable, affordable housing solutions in regions with abundant natural resources like pineapple leaves. Further research and collaborations will be essential to ensure the successful implementation and scaling of this innovative method.

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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Classification Tests.

- IS:2720 (Part 40) – Methods of Test for Soils – Determination of Free Swell Index of Soils. ▫ BS 1377-4 – Methods of Test for Soils for Civil Engineering Purposes – Part 4:

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APPENDIX

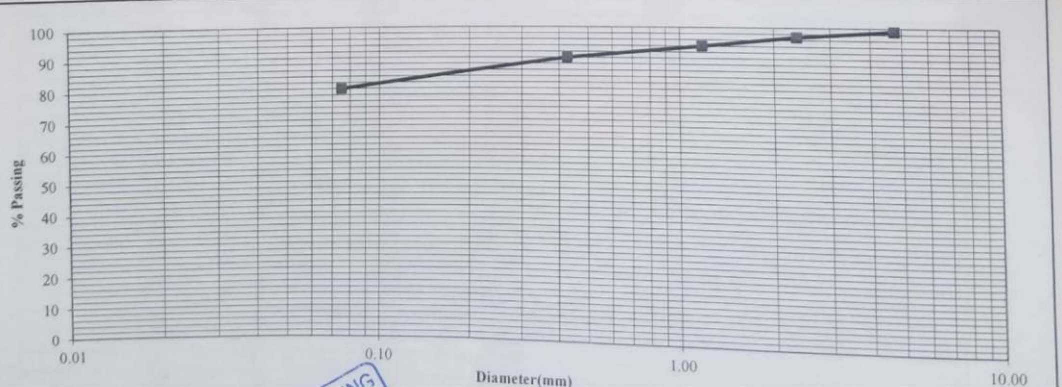
INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	OCHOLLA COLLIN MIKE	Stirling

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

P. O. BOX 795, 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	

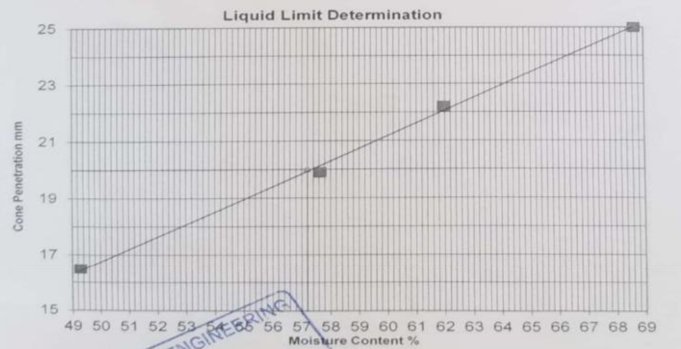
ATTERBERG LIMITS

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

A Centre of Excellence in the Heart of Africa

OCHOLLA COLLIN MIKE & SERIONI BRIAN

TESTING LAB

Stirling

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

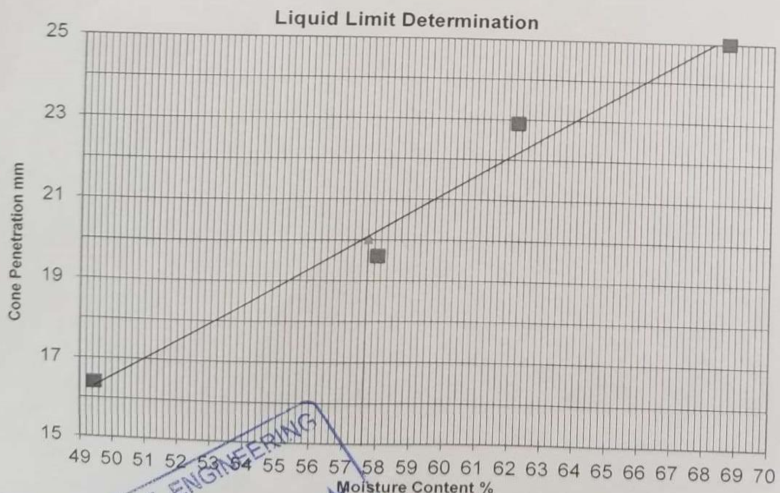
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

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

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
2025
P.O. BOX 796, KAMPALA (U)

Materials Engineer.

Lab Technician

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 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

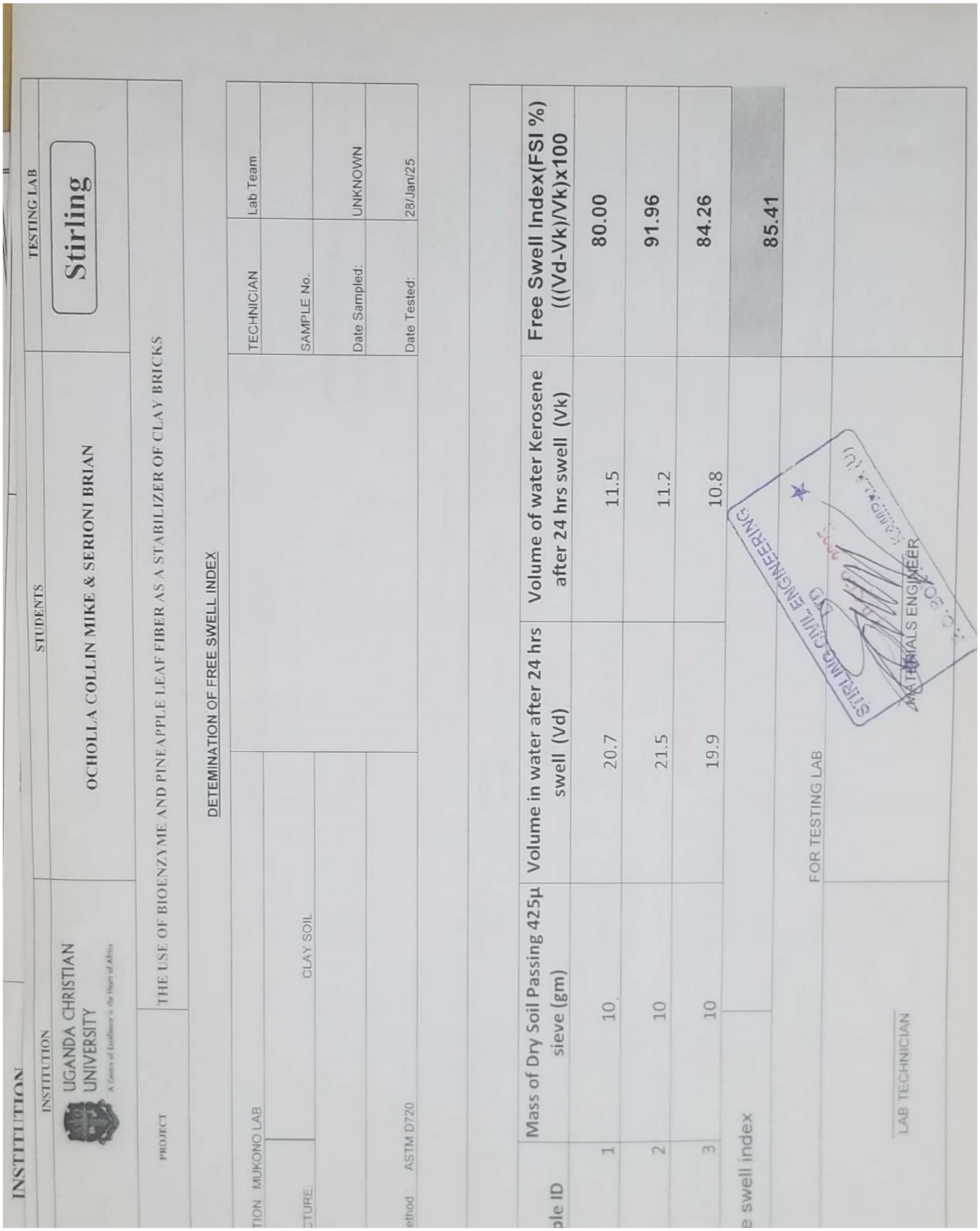
1. Results relate to sample analyzed and are reported as on received basis.

Fwd- 21st/03/25

Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Figure 5 XRF Test of the Clay sample


INSTITUTION

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	

DETEMINATION OF FREE SWELL INDEX

...TION: MUKONO LAB		TECHNICIAN	Lab Team
...CTURE	CLAY SOIL	SAMPLE No.	
		Date Sampled:	UNKNOWN
...ethod: ASTM D720		Date Tested:	28/Jan/25

...ple 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
...e swell index				85.41

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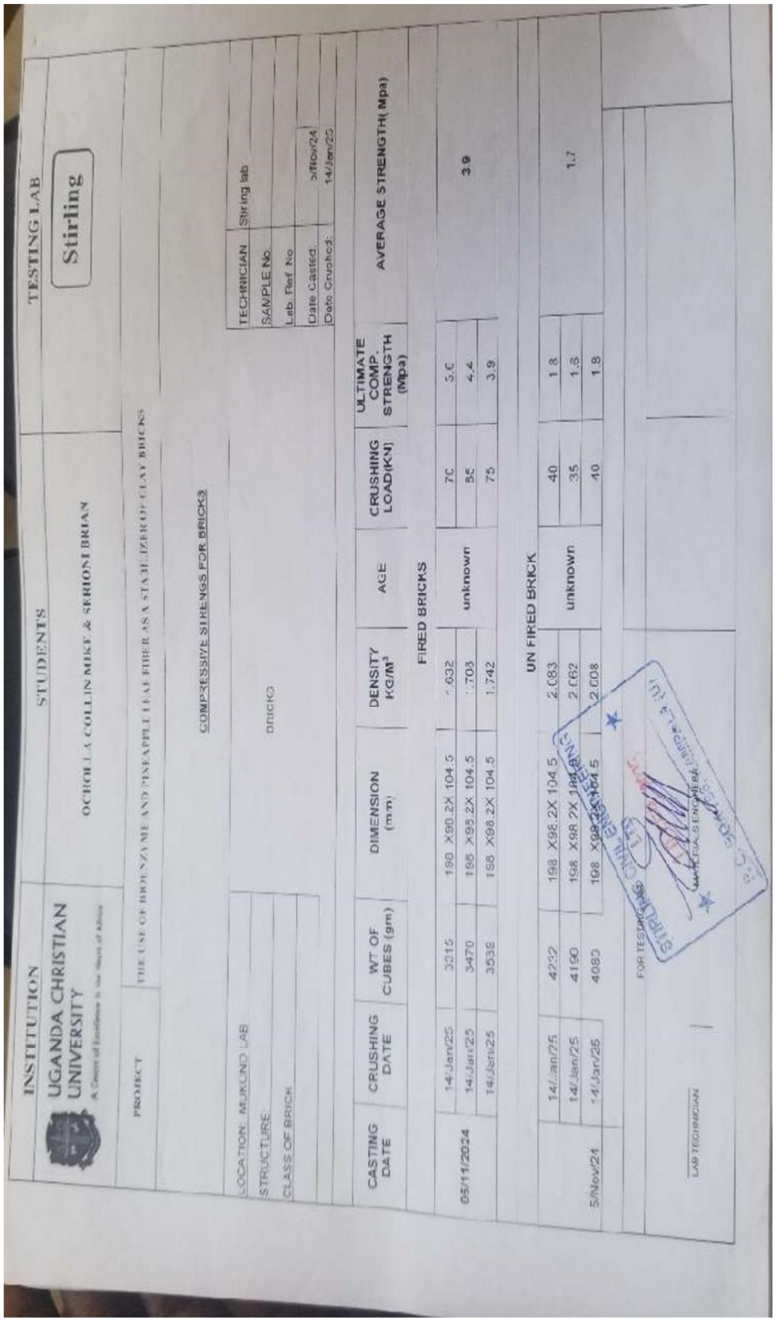
LAB TECHNICIAN

Figure 6 Determination of the free swell index



INSTITUTION: UGANDA CHRISTIAN UNIVERSITY
STUDENTS: OCHOLLA COLLIN MIKE & SERIONI BRIAN
TESTING LAB: Stirling

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

COMPRESSIVE STRENGHS 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/M³	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	3538	198 X98.2X 104.5	1.742		75	3.9	
UN FIRED BRICK								
5/Nov/24	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	
	14/Jan/25	4080	198 X98.2X 104.5	2.008		40	1.8	

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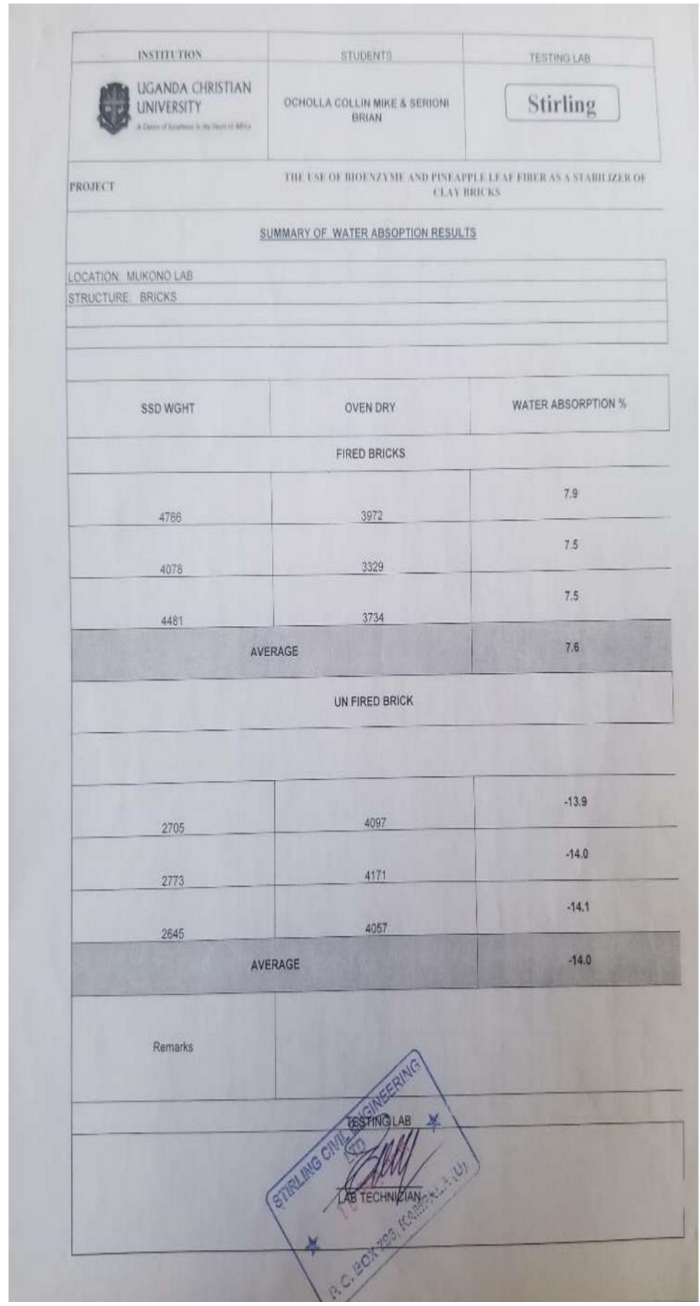
LAB TECHNICIAN



INSTITUTION: UGANDA CHRISTIAN UNIVERSITY
STUDENTS: OCHOLLA COLLIN MIKE & SERIONI BRIAN
TESTING LAB: Stirling

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

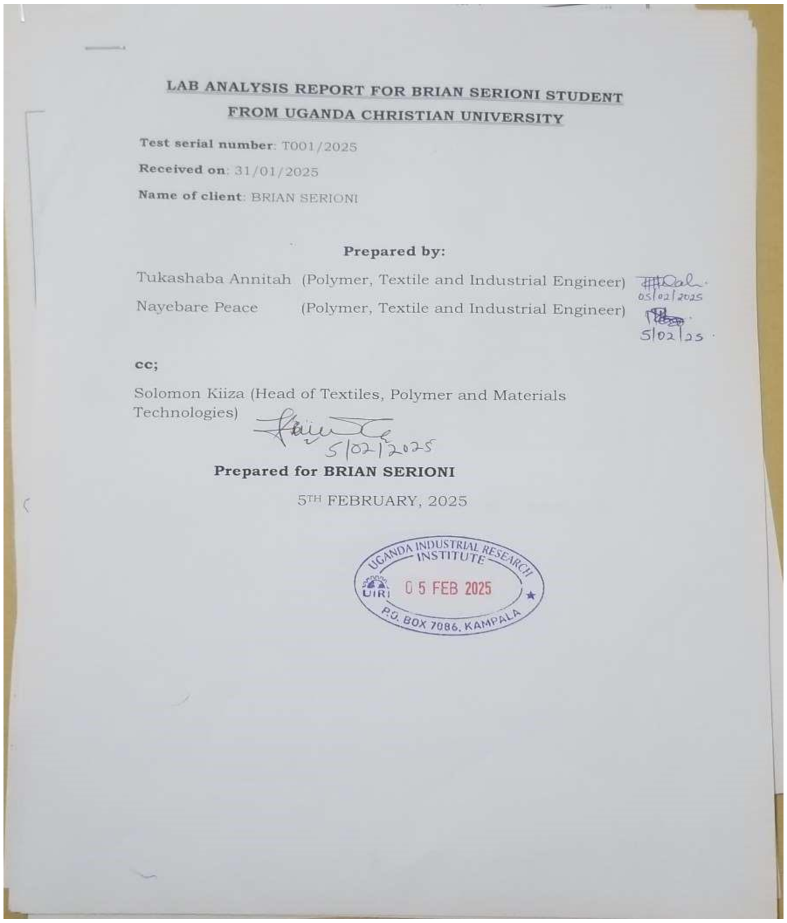
SUMMARY OF WATER ABSOPTION RESULTS

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

Figure 8 Compressive Strengths of a fired and an fired clay brick


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

Figure 9 Lab Analysis Report for PALF

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

TensoMaster
Version 3.1.5

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

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

04-Feb-2025 | 12:58:04 pm

Page 1 of 2

Figure 10 Single Yarn Test

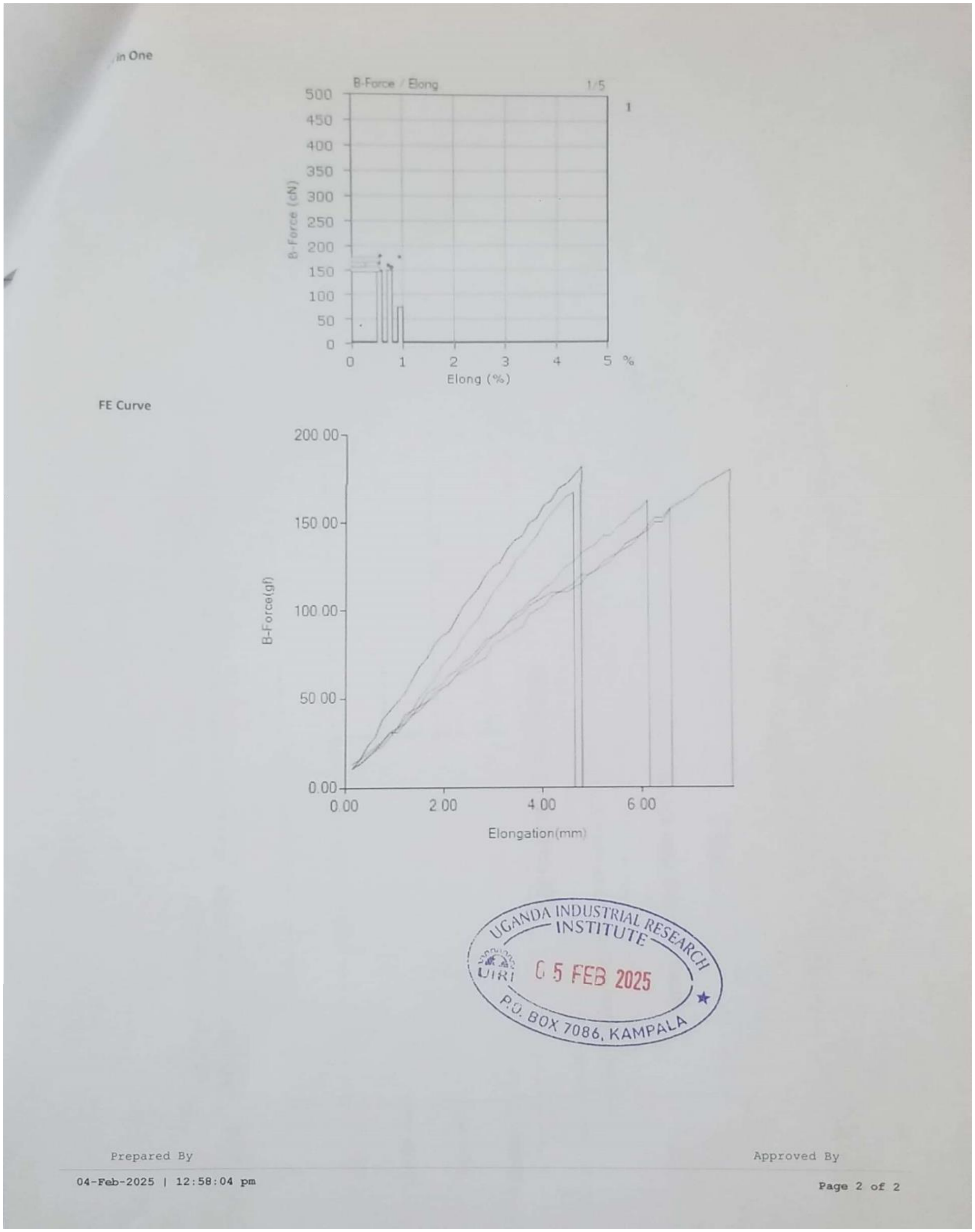


Figure 11 bforce vs eolgation grapgh

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/m^3)	PALF (%)	WT OF BRICK (gm)	DIMENSION (mm)	DENSITY KG/M^3	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 × 63.8	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

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LAB TECHNICIAN

MATERIALS ENGINEER

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Figure 12 COMPRESSIVE STRENGTH TEST RESULTS

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/m^3)	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

FOR TESTING LAB

LAB TECHNICIAN

MATERIALS ENGINEER

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

Figure 13 compressive strength test for unfired bricks (stabilized)

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	217.1 × 102.1 × 65.3	1.464		53.3	2.4

LAB TECHNICIAN

FOR TESTING LAB

MATERIALS ENGINEER

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P.O. BOX 796, KAMPALA (U)

Figure 14 Compressive strength test for stabilised bricks set 2

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	OCHOLA COLLIN MIHE 121332/128	Stirling

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

Bio-Enzyme (ml/m³)	PALF (%)	Initial Weight (g)	Final Weight (g)	Water Absorption (%)	MEAN Water Absorption (%)
0	1	2985	2605	-12.73	-12.89
0	1	2967	2586	-12.88	
0	1	3024	2631	-13.01	
0	2	2928	2552	-12.45	-12.46
0	2	3067	2680	-12.64	
0	2	3024	2653	-12.29	
0	3	2917	2557	-12.04	-11.98
0	3	2994	2639	-11.86	
0	3	3078	2708	-12.02	
50	0	3064	2806	-8.44	-8.48
50	0	3120	2858	-8.43	
50	0	3027	2759	-8.58	
50	1	3270	3015	-7.83	-7.86
50	1	2926	2695	-7.9	
50	1	2968	2737	-7.84	
50	2	2990	2776	-7.18	-7.22
50	2	2887	2678	-7.3	
50	2	3083	2861	-7.17	
50	3	3072	2860	-6.88	-6.87
50	3	3002	2796	-6.84	
50	3	2957	2754	-6.9	
100	0	2880	2895	0.53	0.53
100	0	2937	2953	0.56	
100	0	3060	3076	0.51	
100	1	2983	3026	1.46	1.32
100	1	2966	3003	1.27	
100	1	3040	3078	1.24	
100	2	3093	3151	1.88	1.36
100	2	3021	3072	1.72	
100	2	3035	3085	1.58	
100	3	3110	3155	1.47	1.64
100	3	3014	3068	1.79	
100	3	2975	3026	1.7	
150	0	3054	3016	-1.27	-1.21
150	0	2979	2940	-1.35	
150	0	2971	2943	-1.02	
150	1	3102	3054	-1.58	-1.57
150	1	2977	2931	-1.58	
150	1	2788	2745	-1.56	
150	2	3028	2972	-1.9	-1.85
150	2	2968	2916	-1.78	
150	2	2977	2921	-1.88	
150	3	3036	2964	-2.37	-2.47
150	3	2987	2911	-2.46	
150	3	3017	2940	-2.58	

STIRLING CIVIL ENGINEERING LTD

Testing Lab

Materials Engineer

P.O. BOX 798, KAMPALA (U)

Figure 15 Water absorption for stabilised bricks

Figure 16 Clay extraction site in Siron village

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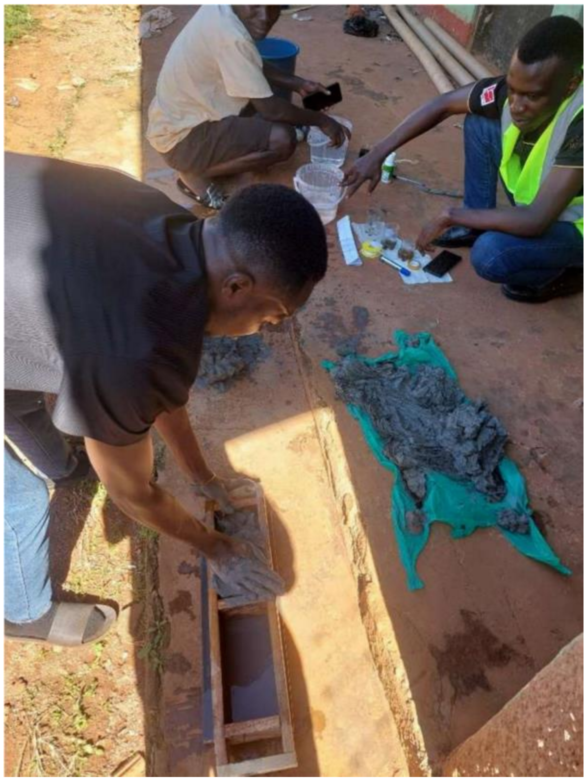


Figure

Figure 15 Mixing of Bio enzyme in required ratios

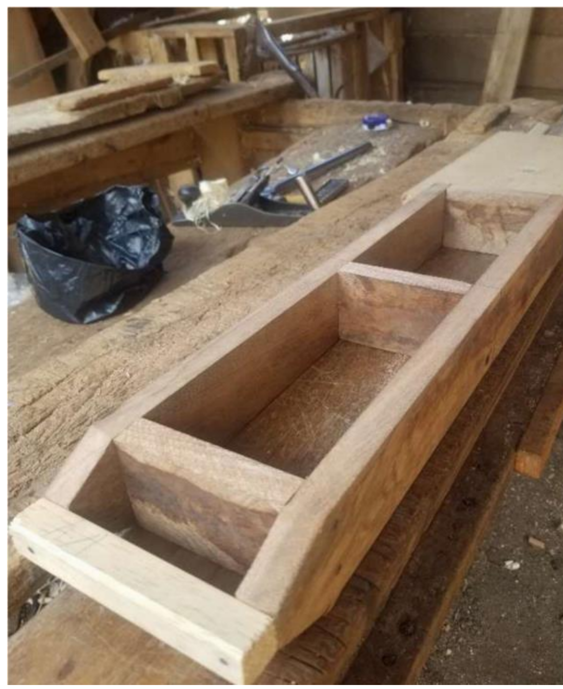


Figure 16 Mold making

INSTITUTION | STUDENTS | TESTING LAB

UGANDA CHRISTIAN UNIVERSITY
A Centre of Excellence in the Heart of Africa

OCHOLLA COLLIN MIKE & SERIUNI BRIAN

Stirling

PROJECT: THE USE OF BIDENZAME 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 X90.2X 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								
5/Nov/24	14/Jan/25	4232	198 X98.2X 104.5	2.033	unknown	40	1.8	1.7
	14/Jan/25	4190	198 X98.2X 104.5	2.062		35	1.6	
	14/Jan/25	4080	198 X98.2X 104.5	2.008		40	1.8	

FOR TESTING

LAB TECHNICIAN

Figure 18 Compressive Strength Test for unstabilised bricks

Figure 19 Tests on the Pineapple leaf fiber

Figure 20 Bio enzyme and proportioning containers

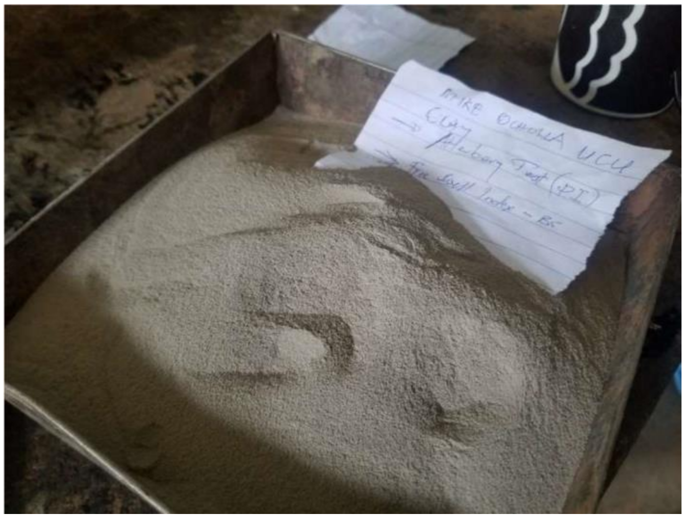


Figure 20 Failed unburnt clay brick in water absorption test

Figure 21 Compressive Strength Test

Figure 22 Failed Unfired clay bricks in water absorption test

Figure 23 clay soil Preparation for Sieve Analysis

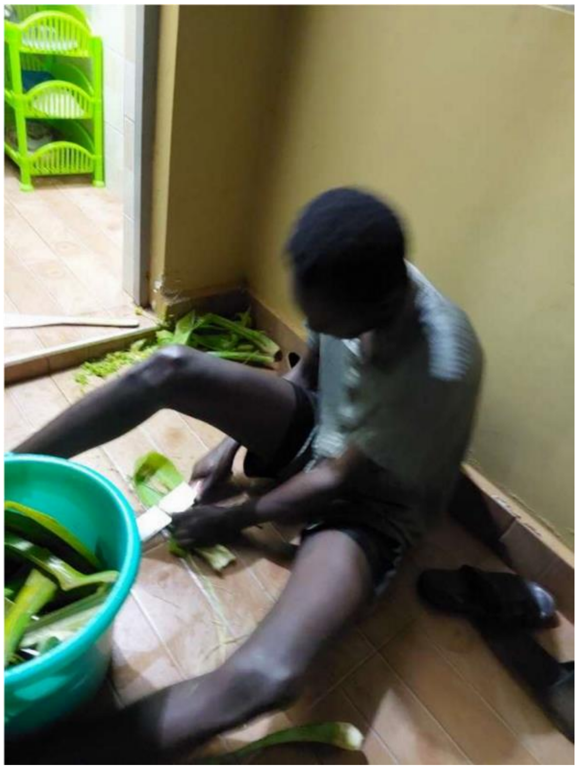


Figure 24 PALF extraction

Figure 25 Extracted PALF

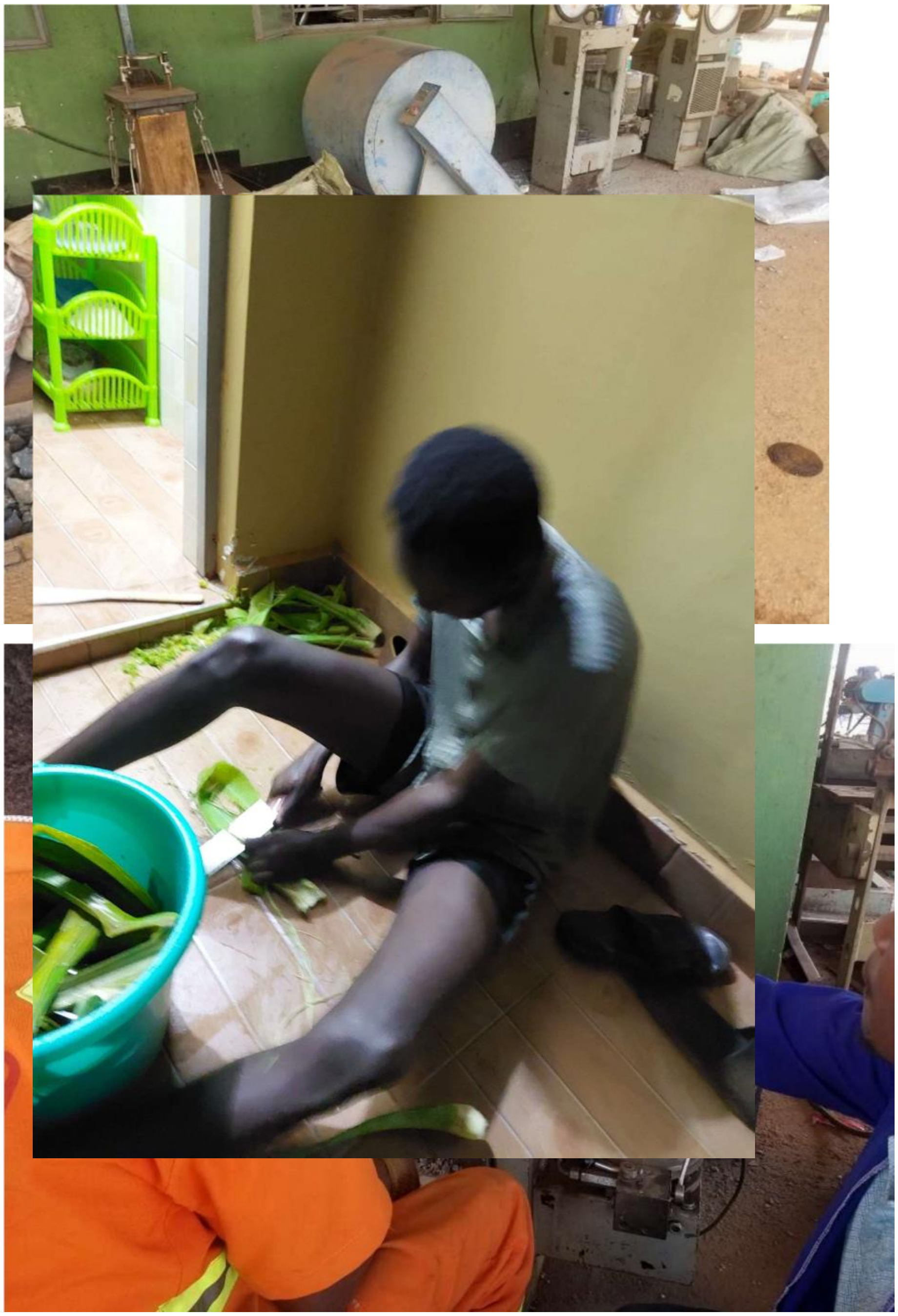
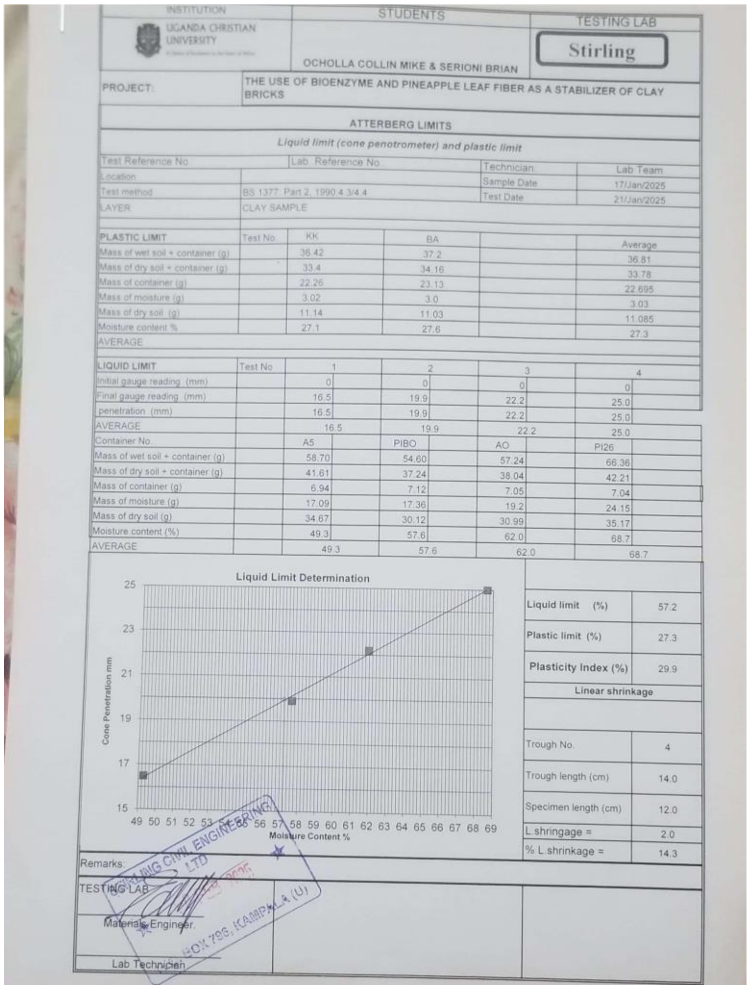


Figure 26 COMPRESSIVE STRENGTH TEST



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 Determination

Cone Penetration mm

25
23
21
19
17
15

49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69

Moisture Content %

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

CIVIL ENGINEERING LTD

BOX 796, KAMPALA (U)

Figure 27 aTTERBERG LIMIT TEST RESULTS

Figure 28 CLAY EXTRACTION SITE

Figure 29 BIO ENZYME

Figure 31 WEIGHT OF THE SAMPLE

Figure 30 MEASUREMENT OF THE TENSILE STRENGTHS OF THE FIBRE

COMPLIANCE MATRIX	
COMMENT	COMPLIANCE
How were the fibers prepared	
Improve the recommendation and conclusion	
Improve the design and the engineering drawings	
Carry out SEM analysis to check the fiber matrix interaction	