DETERMINING THE SUITABILITY OF USING STEEL FIBRES FROM USED TYRES AS A REINFORCEMENT IN AN UNFIRED EARTH BRICK : A CASE STUDY BUGONYA VILLAGE GADUMIRE SUB-COUNTY KALIRO DISTRICT

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ABSTRACT

Unfired Earth bricks are widely used in construction especially in the lower income areas of the world. However, unfired brickwork is less strong than blockwork or fired clay masonry, and at the moment its use is not advised for thin-walled earth masonry in high-load structural applications. Unfired earth bricks also do not carry as great a load from fixings.

With that in mind, this research banks on the knowledge of soil properties to design appropriate geotechnical and geological investigations into the search for the most suitable material for earth construction. From the research below, conversely, the addition of 8% steel fibres from waste tyres by weight in earthen construction will enhance ductility, tensile strength, erosion resistance, and dimensional stability, while reducing shrinkage cracking in the materials.

DECLARATION

I Mulondo Yoab, hereby declare that this research and design report is my own work of commitment and has never been submitted in any other institution (University) for any award of academic qualification.

MULONDO YOAB

S21B32/102

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

APPROVAL

I hereby certify that MULONDO YOAB reg no: S21B32/102 conducted his research study from Uganda Christian University September 2024, to April 2025. This report is therefore a true record of the work he was able to take part in under my supervision and it is now guaranteed ready for submission to the Department of Engineering and Environment, Uganda Christian University.

SUPERVISOR'S DETAILS

ENG. TOM MORE MWANJE

Signature ………………………… **Date………………………………………..**

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DEDICATION

I dedicate this report to my beloved parents, friends and all well-wishers. Remembering with gratitude all your continued encouragement and support to me spiritually, emotionally, financially and socially. You are an inspirational and unforgettable family. I treasure and adore all your endeavors so much. May the Almighty God continue to bless you.

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LIST OF ACRONYMS

Kwh………Kilowatt hour

KN ………………………………………………………………………..…………………………….Kilo Newtons

LL …….Liquid Limit

MM……………………………………………………………………………………………………..……..Millimetre

MPa…………………………………………………………………………………………………….….Mega Pascal

PI……………………………………………………………………………………………………….Plasticity Index

PL………Plastic Limit

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND

The usage of unfired earth bricks was noticed in construction even in ancient civilizations of Egypt, Mesopotamia, and the Americas where they were prepared by mixing sand, clay, straw, and water in the shape of bricks and sundrying them. These materials were locally obtained and in plenty making them easily available to early builders. The earth's thermal properties also provided a natural insulation (Burnett L, 2020).

Europeans used much of the adobe construction in the Middle Ages, especially Portugal and Spain, while the art of construction made its way to Latin America after colonization. Over time, various cultures modified the use of this basic technique to fit environmental conditions. In the United States Southwest region, for instance, the Pueblo community built large structures by using adobe bricks (Hassan M, 2022). During this time, there has been revival of interest in using unfired bricks basically due to their sustainability-from-firing practices as they cause minimum carbon footprints compared with fired bricks, and they can also help regulate indoor temperatures.

Modernization has put the qualities of unfired earth bricks into diverse uses even in the present-day architecture. This has given rise to emerging techniques that harness their durability and structural integrity. Stabilized clay with lime or cement is among the new-fashioned ways.

The adoption of unfired clay brick has been reported as one of the alternatives of reducing energy consumption. This interest in keeping strength requirements up for unfired clay bricks is currently on the increase in demand. Among the materials under testing for compressive strength are bricks.

Compressive strength remains the essential parameter to be considered in the design of bricks. The loads acting on bricks in service are compressive in nature; their reliability in resisting such loads without failure is hereby considered. Thus, the quality of bricks depends on their compressive strength.

Conversely, unfired brickwork has lower embodied energy when compared to blockwork or fired clay masonry, while also being easier to recycle and dispose of at end of use. Unlike blockwork or fired clay masonry, unfired brickwork is susceptible to moisture penetration, so detail design must ensure it remains dry during and after construction.

Over the past 10 years, rapid population growth and changes in land usage have increased demand and the number of vehicles on the road, thus increasing tire waste. Tires pollute the environment. An estimated one billion tires are discarded across the world every year. The materials are slow in natural degradation, and labor-intensive to reclaim, thus tire recycling is viewed as a sustainable solution.

Steel fibres can be up to 15 percent of the weight of tire crumbs with corresponding mechanical properties similar to that of industrial fibres. Unfired earth blocks are also a potential low-cost building alternative considering their low energy consumption in the burning process and transportation of materials.

From [Sukontasukul et al ,2019], The use of steel fibers was found to enhance the flexural action of soil materials. Tajdin et al. used three fiber types, jute, steel, and polypropylene, in reinforcing soil materials, and results indicated improvements in compressive, tensile, and flexural strength.

Generally, unfired brickwork is less strong than blockwork or fired clay masonry, and at the moment its use is not advised for thin-walled earth masonry in high-load structural applications. Fired bricks also will not carry as great a load from fixings. Hence, knowledge of soil properties might be of importance towards the designs of appropriate geotechnical and geological investigations into the search for the most suitable material for earth construction [Da Silva. S, 2021].

To counteract the above harmful effects, the soil can be stabilized. Stabilization improves the characteristics of the soil resulting in masonry units capable of carrying greater loading and better performing when subjected to natural degrading elements. There are several types of stabilization: the first is mechanical stabilization, the second is physical stabilization, and the third is chemical stabilization [Younsi Z, 2023].

Examination of deeper scientific results led to the conclusion that steel fibers act in the manner of springs by helping the masonry unit absorb a vast deal of plastic energy. [Babu and Vasudevan, 2021] investigated shear strength of coconut fiber reinforced soil stating that culms when randomly mixed with soil improves shear strength. Fibers improve the pull between the soil particles while interaction of the fibers among themselves and flexibility of the fibers due to their behavior will be like a structural mesh that will hold the soil together. This gives strong integrity to the soil structure for absorbing huge plastic energy resisting high deformation without disintegration completely.

Unfired earth bricks have always remained very much relevant over time simply due to their practicality and environmental benefits. Even today, they are still a very important material in sustainable building practices as they demonstrate a truly close bond with local resources and traditional craftsmanship.

Earth bricks are of very low cost, energy efficient (they have excellent thermal properties, and very low energy needed to produce), ecological and safe . These characteristics are very relevant and important with the growing need to bring awareness of reduced consumption of energy across the world. However, earth construction techniques like wattle-dab, cob, and adobe need continuous maintenance for holding them in good condition. Their major limitations include water penetration, wall erosion at lower parts due to splashes of water from ground surfaces, damage from termites and pests, and need for high maintenance requirements, among others (Obinwanne Ugwuishiwu et al., 2018).

For nearly a decade now, scientific research has been attempted in the area of usage of recycled industrial tire materials to enhance the properties of concrete , such as the use of ground rubber from tire in bitumen for road constructions . Some researchers have focused on the results of these studies on possible uses of recycled steel fibers. Several scientific investigations proved that using recycled steel fibers in concrete would enhance the brittle matrix, toughness, and post-cracking response of concrete for structural applications . Adding tyre steel fibers 0.13%–0.46% by volume retained the strength to flexure of concrete but did not change the compressive strength for the same concrete mixes (Senesavath et al., 2022).

1.2 PROBLEM STATEMENT

The use of earth as a building material has been commonplace for many years, Historically, earth has been used for construction purposes for approximately 9000 years and continues to be a commonly used building material especially in the rural areas of Uganda [Shantanu. P, 2022].

Bugonya village in eastern Uganda receives a lot of rainfall due to its location in the tropical rainforests area. This has led to bricks made of unfired earth in this area being prone to deterioration when exposed to adverse weather conditions like this torrential rain [I. Alam, A Nasser and A Shah., 2022].

Owing to low strength characteristics of soils used in making the bricks in Bugonya village with the soils having predominantly high moisture content, the bricks made have high water absorption ratio. This makes them unfit to be used for superior work of a permanent nature due to their resulting high shrinkage and low compressive strength of 1.54 N/mm^2 which is lower compared to the minimum standards requirements for a first class brick of $10N/mm^2$.Their brittleness and tensile strength are low too [Sanya. T, 2021].

The durability and strength of the unfired bricks in general are lower than those of fired or concrete bricks [Muheise-Araalia. D, 2021].

On that note however, further research is required to gain deeper knowledge of soil properties for the design of proper geotechnical and geological investigations to search for more fitting materials for earth construction especially when salvaged steel fibers from waste tyres should be used [Eko M, 2021].

This study shall deploy the salvaged steel fibres in strengthening unfired mud bricks for improved physical and engineering properties. The result will thus lead to an alternative which is more environmentally friendly and cheap compared to the energy-hungry fired-brick production with a high carbon footprint, and expensive in the rural community.

Scope, Bugonya village, Gadumire sub-county, Kaliro district. 33^0 29' 15" East

1.3 OBJECTIVES OF THE STUDY

1.3.1 MAIN OBJECTIVE

To determine the suitability of using steel fibres from waste tires as reinforcements in the unfired earth brick.

1.3.2 Specific objectives

1. To determine the physical and mechanical properties of soil to be used for making the earth bricks

2. To determine the effect of salvaged steel fibres from waste tyres on the compressive strength and water absorption properties of unfired earth bricks.

3. To determine the optimum steel fibre content for mix in the bricks during reinforcement.

1.4 RESEARCH QUESTIONS

1.What are the physical and mechanical properties of the soil to be used in making the earth bricks?

2. What is the effect of salvaged steel fibres from waste tyres on the compressive strength and water absorption properties of unfired earth bricks ?

3. What is the optimum steel fibre content for mix in the bricks during reinforcement ?

1.5 JUSTIFICATION

Inclusion of fibres in the clay matrix enhanced the resistance against shrinkage, abrasion and erosion . [Sujatha and Devi, 2018] and [Sharma et al, 2021] observed a decrease in shrinkage as the fibres inhibit the propagation of cracks and also bridge them . The shrinkage decreased with the increase in fibre content.

Steel has a high durability, ductility, tensile strength, corrosion resistance and hardenability hence making it a strong additive to strengthen the unfired earth brick [Ubong A, 2023].

The use of Fiber reinforcement in stabilizing earthen structures seeks to improve the ductility, toughness, tensile strength, and durability of the stabilized soil in addition to increasing its strength [Wada P, 2021].

Steel fibres in the clay matrix act as springs and absorb a great deal of plastic energy and also resist deformation without full disintegration.

Steel from waste tyres has a good adhesion with proven mechanical strength of upto 2165 MPa thus making it an ideal additive to the unfired earth brick .

On carrying out experiments including density, water absorption, shrinkage, compressive strength, tensile strength, wearing and erosion on soil blocks made with two soil types and enhanced with three fibre types at 0.25–1 weight percent. It was found that the physical, mechanical and durability properties of the blocks were generally improved and a recommendation of 0.5 weight percent fibre content and high clayey soil are made [Danso et al, 2022].

The improved performance is attributed to a fair increase in clay content in the soils employed, thereby enhancing cohesion and elevating strength (Krishnaiah and P. Suryanarayana Reddy, 2008). Another possibility could be tied to the fibrous nature in the composition, as the fibres could cut down on its hygrometric shrinkage and release water at a slow rate (Sasui et al., 2018; Quagliarini and Lenci, 2010; Mbereyaho et al., 2019). However, this compressive strength is still less than that obtained when cement was used as a stabilizer (Patowary, et al., 2015). This indicates that the manufacture of unfired earth bricks would be suitable for use in single-story buildings.

The addition of fibrous materials in earthen construction will enhance ductility, tensile strength erosion resistance, and dimensional stability, while reducing shrinkage cracking in the materials (Walker, 2004). To vouch safe earth brick applications, weather resistance will be made an important recommendation (Ukwizagira & Mbereyaho, 2023).

The reinforcement of the soil using fiber has been the most preferred idea in geotechnical and geoenvironment engineering. Soil reinforcement is brought about using randomly distributed discrete fibers to be modeled as grass and/or plants growing on a slope to be effectively stabilized. This is more simple compared to soil-reinforced discrete short fibers which can maintain isotropic strength without introducing possible weak planes compared with conventional geosynthetics reinforcement methods. Fiber-reinforced soil is like a composite material in that the fibers serve to improve on the strength of the soil. Shear stresses on ground facilitate improved tensile strength for the fibers which in turn resist greater the soil. The use of fibers in soils is very closely matched to the response of plant roots such that they add resistance to geotechnical and geoenvironmental load which subsequently contributes to soil stability at near-surface soils in which effective stress is low (Medina-Martinez et al., 2022).

Adding fibers to soil greatly increases its resistance to non-elastic shrinkage, cracks, impacts, etc. Thus, fibers act as strengthening agents for earth blocks enabling them to absorb more energy and resist more loads, making them a viable product in the earthquake-prone areas. The incorporation of fibers, apart from strengthening, contributes to the resistive property of earthen bricks to deformability. Concurrently, it was found that reinforced earth blocks contain less water retention.

Typically, conventional options would offer less. The use of chemical and synthetic fibers as stabilizers and reinforcers results in a stabilized block with a strength above twice that of a normal stabilized block. To strengthen this theory results from laboratory investigations complemented implementing the potential application of fibers in earthen materials which subsequently would enhance the resistance against plastic shrinkage, impact and increased toughness . Studies have shown a considerable enhancement in post crack flexural behavior as compared with blocks without reinforcement. Fiber addition enhances the sorptivity behavior as it improves the bond matrix. This is confirmed by studies from author C.K. Subra-manian Prasad et.al. when the fiber content was constrained. When kit fiber and bottle fiber were compared, they later showed more sorptivity. Sergio Neves Monteiro Proclaims that fibers should be even more concentrated for an end with standing block (Jesudass et al., 2020).

Unreinforced blocks were observed to fail suddenly with one large crack, whereas sugarcane bagasse fibre reinforced soil blocks failed gradually with multiple finer cracks. If the failure is described as more gradual, then it acted more like a ductile material than a brittle one, thus supporting more loads before disintegration Bouhicha et al. (2005) and Cai et al. (2006). When blocks were pulled from the testing machine, while they split into two halves, these were still held together by the fibre. Therefore, this indicates that fibre-enhanced soil blocks fail slowly, rather than suddenly, and will support a load for a while after their failure (Danso et al., n.d.).

Firing is done for strengthening the clay soil to become as tough as stone. Unfortunately, the process of making per one fired brick emits 0.4 kg of CO2 and consumes about 2 kWh (Munoz Felasco et al., 2014). Earlier researches on the production of unfired clay bricks have incorporated added materials as reinforcements that commonly form the so-called reinforced bricks. Some of those studies used natural plant fibers such as straw (Binici et al., 2005), sisal (Njau and Park, 2015), coir (Danso et al., 2015; Salih et al., 2020), and sugarcane (Saccharum officinarum) bagasse fiber (SBF) (Danso et al., 2015; Salih et al., 2020).

Cement is also a popular choice when added to clay bricks because of its good mechanical properties; however, this very marble cement is not favored environmentally due to the associated high energy consumed and CO2 released in the process of making cement (Zhang, 2013; Marcelino-Sadaba et al., 2017; Joglekar et al., 2018). The production of one tonne of cement consumes around 5.6 GJ of energy and gives out about one tonne of CO_2, contributing 7% of emissions into the atmosphere (Shubbar et al., 2018). Therefore eco-friendly reinforcement or stabilizer must be employed to produce unfired clay bricks (Danso et al., 2015).

CHAPTER TWO : LITERATURE REVIEW

2.1 INTRODUCTION

In times where construction activities are increasingly having adverse impacts on the environment, sustainability and environmental friendly alternatives are much so required to serve as alternatives to the traditionally available building materials. Unfired bricks in specific are a very viable option for attaining sustainability since they require available natural materials and their production consumes low energy levels. Their production also excludes burning which leads to maintenance of specifically low carbon foot print.

The selection for use of these unfired earth bricks in enhanced load bearing structures is still restricted due to their inherently low mechanical strength and other structural weaknesses more so related to withstanding loads and abrasion from external factors (Asha C et al, 2023). Various researches have incorporated a vast number of reinforcement techniques to boost the strength performance and durability of the earth bricks mainly through the use of natural, synthetic fibers to a certain extent industrial by products too. However, a reliable solution could arise from the use of steel fibers from waste tyres as a reinforcement element in the unfired earth bricks.

Earthen bricks are still more brittle and weaker in compression and bending vis a vis concrete masonry units and fired bricks . Their compressive strength values range between 1.3 to 4.0 MPa, which is greatly lower than burnt bricks and concrete blocks, which average between 17.24 MPa and 13.10 MPa, respectively .

Application of steel fibers can improve ductility, thus in the wake of a disaster will delay catastrophic failure in effect giving building occupants time to escape, as opposed to facing the risk of injury or even fatality because of sudden failure.

Conversely, synthetic fibers such as steel are known to enhance concrete freeze–thaw resistance, impact resistance plus mitigate shrinkage cracking. In soils used for geotechnical applications, the addition of isotropically distributed steel fibers better the unconfined compressive strength, ductility, residual strength, absorbed energy, flexural toughness, and splitting tensile strength of soil mixtures.

In other studies, where steel fibers have been added to cement based materials the tensile and flexural strength was enhanced which implies that such positive action can be advanced to earth bricks. This review therefore is aimed at in depth examination of the existing knowledge sources about the use of fiber reinforcement in earth bricks with keen attention on mechanical performance, durability and sustainability in the use of fiber-reinforced unfired earth bricks.

2.2 RESEARCH CONSTRAINTS

In the body of research available about reinforcement of earth bricks, studies are majorly concentrated on natural and other synthetic fibers which has left the potential of steel fibers from waste tyres largely unexplored. This calls for comprehensive studies on how varying amounts of steel fibers could affect the mechanical properties and further determine the optimal fiber content for maximum brick performance.

2.3 OVERVIEW

The increase of the population and urbanization in Uganda has led to constant demand for transportation efficiency coupled with the change in living standards that all call for vehicle purchase. This all comes with tyre production from which the tyres come to become waste after their initial functionality is done. 10-15% of the entire mass of tyres is the steel fibers depending on the type and size of the tyre in question (Haydar G,2021).

Uganda faces an acute problem with waste tyre disposal, estimates suggest that around 600,000 to 800,000 waste tyres are generated yearly. This problem is exacerbated by the increasing number of vehicles, with many of these tyres being improperly disposed of causing environmental concerns. This situation underscores the need for more effective waste management systems and recycling activities a case in point being reusing these tyres as reinforcements in the unfired earth brick.

Waste tyres are a threat to the environment due to their non-biodegradable nature which implies that once they are disposed into the environment they pose a risk of spreading micro plastics once when they wear out. Once they find their way into water bodies, aquatic ecosystems are distorted and if these aquatic species are consumed by humans the micro plastics find their way into the human gut and pose a health risk to the human consumers (Haydar G,2021). Reusing these steel fibers as a reinforcement in earth bricks will help to reduce the demand for new steel production which conserves natural resources and sustains a circular economy.

The research study will further help in reducing tyre incineration, an activity that increases the carbon footprint in the atmosphere and release of other harmful substances such as sulfur oxides. Through repurposing the steel fibers for use in earth bricks, the need for incineration will be checked. Before addition of new components into any masonry unit, it is key to understand the behavior of its properties under different conditions. Commonly, bricks are made of clay and sand and mixed in various proportions to which sometimes a binder is added. The stabilized block is then pressed into the required shape as per the design requirements and it is either fired or sun dried. For the case of the firing of bricks, environmental degradation is high because a brick kiln emits about 70-282 g of carbon dioxide, 0.001-0.29g of black carbon, 0.29-5.78g of carbon monoxide and 0.15-1.56g of particulate matter per kilogram of brick fired (Phillip Z.2020). About 0.54-3.14 MJ of specific energy are consumed depending on the type of kiln and fuel used for firing.

With the incorporation of fibers and other industrial waste products into the earth brick matrix, variation was noticed in the properties depending on composition and manufacturing procedures. Bricks are graded and classified based on design codes which much so rely on the purpose of the brick and the kind of environmental conditions that they will be exposed to. A thorough study of the material used in the making of bricks and the factors related to the brick properties is highly required for standardization of the bricks.

Reuse of agricultural by-products in bricks presents advantages such as a lower cost and ecological saving not neglecting the fact that natural fiber sources are renewable and environmentally friendly. Earth bricks reinforced by agricultural wastes and other fibers were studied with the equilibrium moisture content for the bricks under different conditions being less than 7% (Anant L et al,2020). The brick physical and mechanical properties were also improved for the different materials used.

Morel et al summarized the mechanical behavior of unstabilised rammed earth produced blocks whose compressive strengths lie in a range of 1.5-3.0 MPa with densities from 1763 to 2160 kg/m^3. He noticed that higher strengths could be reached using a hydraulic press to boost the brick typical compressive strengths hence compaction will also be done in our research.

For dry building elements made of earth the compressive strength of 2-5 MPa should be used (Minke,2019) and also poor earth materials may have strength as low as 1 MPa and the optimums can go as high as 10 MPa. According to (Schroder,2017), numerous factors such as grain distribution, grain quality, clay mineral quality, quantity of clay minerals, binding strength of the materials, preparation and amount of water used in production work of the bricks all influence the dry compressive strength of the earth as a building material.

2.4 STRENGTHS OF UNFIRED EARTH BRICKS

Nondried earth blocks are ecologically friendly; they are manufactured from readily available natural materials with a low carbon footprint and impact. These clay materials for earth blocks naturally insulate against heat and cold in the regulation and control of indoor temperatures. Unfired earth bricks regulate moisture because they can absorb moisture and release some, and this helps to maintain comfortable indoor humidity levels (Alkhatib S., 2023).

According to (Ndyambaje P, 2019), the compressive strength and tensile strength of the modified earth bricks containing synthetic fibres improved over the unreinforced earth bricks, while the optimum modification effect was obtained at 8% by weight of the fibres to soil. This means that the addition of recycled fibres to the matrix of earth bricks positively influences the compressive and tensile strengths of the bricks. This is crucial as the maximum possible compressive and tensile strengths are the parameters that most significantly respectively define the mechanical characteristics of soil blocks. Therefore, it is suggested that the use of 8% steel fiber content by weight is made by the practitioners for improving strength properties in soil blocks.

Such earthen users for construction should go for very clayey soil as it makes earth bricks modified with fibers perform better in carrying as compared to other binders that do better with sandy soils. These modified soil bricks are just apt for use as a building material particularly for developing countries where a housing deficit continues because of the high costs of traditional building materials.

2.5 WEAKNESSES OF UNFIRED EARTH BRICKS

Unfired earth bricks generally have a Compressive Strength lower than fired bricks, making them less suitable for high load-bearing structures in some applications . They have, therefore, been further disqualified for use in high-load-bearing structures. Their susceptibility to fading and weathering is a cause for concern. It is not only the cases of excessive precipitation and prolonged moisture exposure that will cause damage, but also the case of the lack of proper sealant or even protection treatment (Kannan G, 2023).

Limited Structural Applications: While extra-low low-strength bricks are in their application domain for small-load structures, strength requirements that they may fall short of for high-loading applications may call for supplementary reinforcement. Besides, unfired earth bricks may also require extensive maintenance to ensure longevity, particularly in climates with extreme weather conditions. Production by all means of unfired earth bricks is labor-intensive, where the process is very time-consuming and labor-intensive when compared to the automated production of fired bricks (Sharma T, 2023).

According to the series of inspections outlined above, they are an excellent candidate for an alternative green building material, especially in some climate and building typologies. The strengths in thermal performance and sustainability have to be offset against some weaknesses in structural capacity and weather resistance.

Table 2-1: Unfired Earth Brick Specifications

Number	Detail	Sizes	Units
1	Size	200x150x90	mm
2	Thickness	50,75,100,125,150,175,200,225	mm
3	Compressive strength	>3-4.5 (IS 2185)	N/mm^2
4	Normal dry density	450-650	Kg/m^3
5	Thermal conductivity, k	0.96-0.98	W/MK
6	Thermal resistance	0.46	$K\text{-}m^2/W$
7	Heat transmission coefficient, U	2.47	W/m^2k
8	Drying Shrinkage	0.7 % (Size of bricks)	%
9	Sound Absorption	Up to 42	De
10	Fire Resistance	2 to 6	Hrs

2.7 WHY USE STEEL FIBRES?

When steel fibers are introduced into brick materials, they help in developing tensile and flexural strengths in bricks so that they endure stresses during operational times. These fibers could also have differences in flexibility from the regular brick material, which could result in better handling and performance on all surfaces (Paul S, 2022) .

Since the soil is basically clayey-silty, the clay acts like cement in concrete, bonding the larger particles in the brick. Silt acts as a filtering agent for the soil and is really aggregates which need binding forces. Steel fibres act as binding agents by bridging cracks in the soil matrix thus serves that need.

Using salvaged steel fibres as additives in earth bricks decreased erosion rates from soil blocks sprayed with water. This shows that the modified earth bricks resist erosion better than unreinforced earth bricks. This resistance will assist construction workers in fighting the durability challenge in earth structure construction.

Fibers are also very likely to prevent all those challenges which earth construction would have suffered like reduction of strength and durability.

The type of soil from which soil blocks are manufactured is important because soil happens to be the major material which is present not less than 90% in any reinforced soil block. This indicates that clay soils perform quite well.

Steel fibers can thus ensure very good adhesion with the clay matrix, improving the overall performance of bricks and reducing chances of disintegration. From the sustainability point of view, Steel fibers add a very little weight compared with the advantages derived from using them in bricks. Therefore, the idea should be practical when it comes to improving the performance of bricks without considerably increasing the mass of the bricks (Singh S, 2021).

Steel fibers can provide insulation to bricks made from clay matrix so that they can regulate the temperature well thereby making them energy efficient.

Steel fibers would improve the water resistance of bricks as they would create a denser material thereby reducing the porosity, thus improving the resistance to water absorption as seen in reinforced samples (Beddar, M, 2024).

2.8 STEEL FIBRE COMPOSITION

Tyres are a homogenous product with an average composition as follows;

1. Carbon 70-75%,
2. zinc oxide 1.2-2.0%,
3. hydrogen 6-7%,
4. sulphur 1.3-1.7%,
5. iron 13-155 and additives 3.5-5%.

2.9 PHYSICAL PROPERTIES

Length and Diameter: Steel fibers are mostly fine and can vary in diameter (mainly around 0.1 mm to 1 mm) and lengths (from a few millimeters to several centimeters).

Shapes: Steel fibres can be crimped or straight, which aids in improving bonding with the rubber matrix. In this case we used an isotropic arrangement where steel fibres were randomly mixed into the steel fibres to attain an isotropic end product.

Figure 1: Depicting waste tyres before shredding

2.9.1 GENERAL EFFECTS OF APPLYING ASSORTED SYNTHETIC AND PLANT FIBRES ON BRICKS

Increased Flexural Strength: Fibers like steel, polypropylene, or even natural fibers can augment the flexural strength of bricks, therefore making them less likely to crack under stress. Another observed benefit is on impact resistance since the fibers present in bricks increase shock absorption and decrease the probability of breakage. (Ullah. S, 2024)

Beyond the critical fibre length, increased fibre content induces strength reduction as the fibres begin to knot together (Ismail and Yaacob, 2011), thereby reducing cohesion within the soil (Medjo Eko et al., 2012), and breaking up the soil matrix (Millogo et al., 2014), resulting in reduction in strength of soil-fibre matrix.

Studies examined the influence of recycled steel fibers on the mechanical properties of soil blocks. The addition of fibers in the soil blocks increased the density of the bricks, which could be attributed to the high density of the fiber. This consequently means that when used in the construction of houses, the weight of the entire house is going to be reduced. Earth bricks modified with steel fiber were observed to have a lower water absorption rate, which was attributed to the hydrophilic nature of these fibers; thus, higher steel fiber content within the earth bricks might absorb less water during the rainy season, resulting in positive impacts on some mechanical properties of the blocks.

Higher Ductility: Fibers possess the ability to increase the ductility of bricks, enabling deformation without rupture in seismic regions and in applications involving torsional loads on the bricks. The addition of recycled steel fibers into the soil matrix improves the soil erosion resistance. Stated factors could explain the improved resistance of modified earth bricks because steel fibers prevent water from percolating through the soil particles, thus reducing the erosion effect on the bricks. This is a very useful property in high-rainfall areas where erosion of earth buildings is frequent (Danso et al.,2015).

Steel fibers were used in earth to enhance significantly the deformation characteristics and load-deflection characteristics of unreinforced blocks. The blocks reinforced with steel fibers also displayed ductile behavior after cracking. The ductility was attributed to the fibers bridging the cracks and holding the cracked portions together. Randomly mixing fibers into soil has been shown to increase the shear strength (Babu and Vasudevan et al.). Fibers enhance cohesion among soil particles while interaction among the fibers themselves, along with the flexibility of fibers, allows them to function like a structural mesh in keeping the soil together and improving its structural integrity.

Most of the previously cited research by Morel et al. centered solely on the mechanical behavior of unreinforced rammed earth while compressed earth blocks were manufactured with a manual press. The compressive strengths of these unreinforced earth specimens ranged between 1.5-3 MPa, with corresponding densities varying between 1750-2150 Kg/m3. Reinforcement for this category allows achieving higher strengths and had compressive strengths most commonly lying at about 2-3 MPa-upper using hydraulic presses or some cement contents, Also presenting compressive strengths from 0.6-2.25 MPa for unreinforced earths as cited by Jimenez et al.

Another important aspect of steel fibers in a system is their ability to bridge cracks such that, computed in a tensile sense, after cracking no longer means a fall to zero tensile strength, but where the strength stabilizes to a fairly constant value. In addition, fibers have contributed to concrete that improves its toughness. Toughness is the ability of a material to absorb energy and deform plastically before fracture. This is particularly relevant to structural elements, which may be subjected to dynamic loading (Senesavath et al., 2022).

2.9.2 THERMAL PERFORMANCE

The walls constructed with hypercompacted unfired hollow bricks show the best thermal performance, hence the steel fibres provide the compaction feature, and this is due to the presence of air pockets in the brick holes that significantly retard the heat flow between the outside and inside. In light of the above, thermal performances at the wall scale could be improved further with lightly compacted unfired hollow bricks containing synthetic fibers which combine a low material density, hence low thermal conductivity, with high thermal inertia due to pore water phase changes and extra thermal insulation provided by synthetic fibers and air pockets (Bruno et al., 2020).

2.9.3 MODES OF ACTION OF STEEL FIBRE REINFORCEMENT IN BRICKS

2.9.3.1 BRIDGING OF CRACKS

When microcracks start forming in the brick due to shrinkage drying or through load application, steel fibres span across these cracks. The fibres tie through the gaps, keeping the crack faces together and preventing their widening. This delays brick failure.

2.9.3.2 STRESS REDISTRIBUTION

This harnesses ductility and the brick's ability to absorb and dissipate energy without britte failure.

2.9.3.3 PULL-OUT RESISTANCE / MECHANICAL ANCHORAGE

The fibres are hooked into the soil matrix. When stress is applied, they resist being pulled out.

Hooked or crimped fibres increase this pull-out resistance via mechanical intertwining, providing better post-crack performance.

The bond between the fibre and the soil-cement-clay mix is crucial. In unstabilized bricks, this bond is mostly mechanical (not chemical).

2.9.3.4 POST-CRACKING LOAD CARRYING

After the brick matrix cracks, the fibres continue to carry load a concept known as residual strength. This increases toughness, meaning the brick can deform more without disintegrating.

2.9.3.5 IMPROVED FLEXURAL AND IMPACT STRENGTH

Earth bricks are naturally weak in tension and flexure. Fibres compensate for this weakness, especially under: Bending e.g., lintels, wall panels, Impact loading e.g., earthquakes, debris, Dynamic loads e.g., vibrations

2.9.4 PRODUCTION PROCESS

Mixing and Handling: Generally, the addition of fibers tends to alter the properties of mixing and handling of the brick material. Therefore, during mixing, care must be taken for the uniform distribution of fibers and the use of personal protective equipment.

Material Costs: Although fibers enhance performance, they can equally contribute to production costs. The choice of fiber can greatly influence the costs involved.

While fibers can offer improvements in mechanical properties, durability, and performance under diverse conditions in the brick-making process, their precise effects depend largely on the type and amount of fiber, together with the full composition of the bricks.

2.9.5 ASPECT RATIO

The aspect ratio of the fibers is another main factor in fiber-reinforced blocks. The term aspect ratio refers to the relationship between the length of the fibers and their diameter. Generally, high aspect ratios are known to enhance both the tensile and compressive strengths of the blocks which they reinforced. Generally, the use of synthetic and natural fibers in block reinforcement improves the ductility of the block so that in case of a disaster the block can still tolerate failure for some time giving some time for escape of occupants-thereby reducing casualties or injuries (Nazir M, 2022).

2.9.6 BLENDING CONDITIONS

The consistency of steel fibre-reinforced earth can be influenced by the time and temperature used during blending, thus delicate control is necessary to obtain optimal performance .(Li et al, 2006) investigated the impact of blending time on the permanent changes in synthetic fibres after mixing with earth. The findings showed that varying the blending time (45, 60 and 90 minutes) had no major effect on the properties of modified binders or reinforcements.

Figure 2 : Mixing wet earth with 5mm steel fibres

CHAPTER THREE: METHODOLOGY

3.1 MATERIALS OF STUDY ACQUISITION

3.1.1 STEEL FIBRES

Steel fibres were acquired by extracting them from waste tyres by the process of shredding where steel fibres were pulled out of the tyre structure mechanically using a large hook called a bead extractor in a mechanized setting.

After the steel fibres were extracted from the tyres, they were cut into varying lengths using a cutting disc and homogenously mixed with soil and water and the mixture applied in a Press mold with the soil to make the bricks. Peating was also done using a trowel to prevent exposure of brick fibre tips after production to combat any chance of rusting.

Figure 3 :Removing stuck rubber pieces from the 5mm cut steel fibres

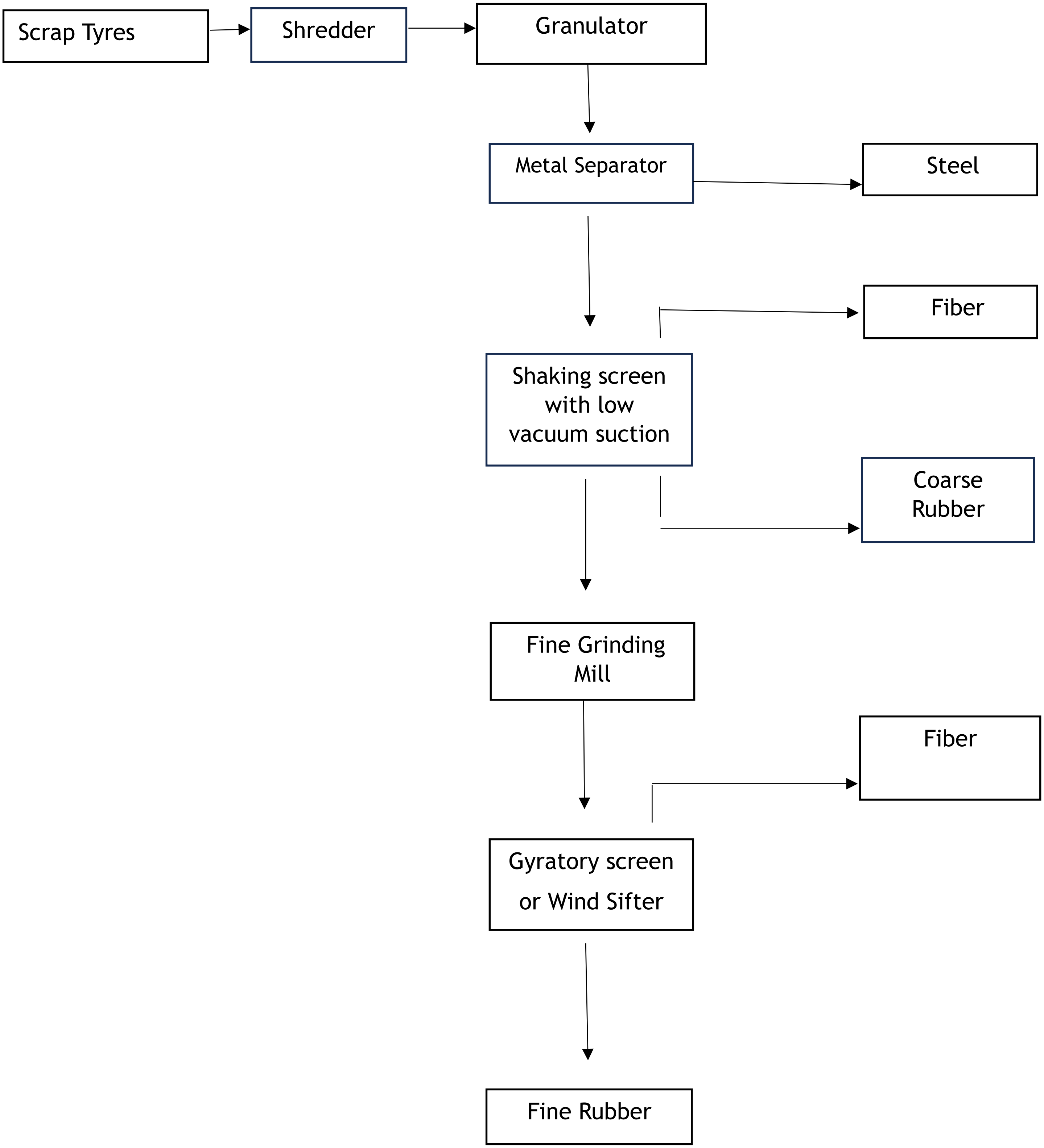
Scrap Tyres
Shredder
Granulator
Metal Separator
Steel
Fiber
Shaking screen with low vacuum suction
Coarse Rubber
Fine Grinding Mill
Fiber
Gyratory screen or Wind Sifter
Fine Rubber

Figure 4: The Industrial process of steel fibre extraction from waste tyres

3.1.2 EARTH

The earth to be used was acquired from Bugonya village in Kaliro district at coordinates of $33^0 29' 15''$ East and was be dug out by hand hoes. Atterberg limits in the soil sample will be determined as per the **BS 1377: Part 2 1990** specification. In addition, the soil material was classified following the **BS 1377: Part 2 1990** specifications and the unified soil classification system (USCS) . Finally, the soil's Optimal moisture content was measured employing the Proctor compaction test as per the **BS 812:103.1-1990** standards .

Figure 5 :Preparation of raw earth for the mixing and molding process

.

Figure 6 : The process of reinforced earth brick making

3.1.3 MATERIALS OF STUDY AND EQUIPMENT TO BE USED

1. Bead Extractor for steel fibre extraction from tyres.

2. A locally made wooden mold to shape the earth into the brick-like shape.
3. Water to use in making of the bricks
4. Hoes to dig out the earth.
5. A block Press for shaping the uniformly and homogenously mixed components into the perfect brick-like shape.

3.2 PARTICLE SIZE DISTRIBUTION

3.2.1 SIEVE ANALYSIS

Sieve analysis was done to determine the particle size distribution of soils following British Standards BS 1377: Part 2 1990 .

Equipment

1) Stack of sieves with a cover,
2) Mortar and pestle or a mechanical soil pulverized
3) Balance, sensitive to 0.1 g
4) Oven
5) Mechanical sieve shaker
6) Brush

Test Procedure

This required mechanically grinding the soil, properly stacking the sieves, weighing the collection pan and each sieve independently, and then calculating the mass of each sieve and retained soil following ten to fifteen minutes of shaker application. The data obtained was useful in deriving correlations as regards porosity and packing. To categorize the soil and identify its best uses, data from the particle size analysis—such as the coefficient of curvature, uniformity coefficient, and effective size—were utilized.

3.2.2 ATTERBERG LIMITS TEST

Atterberg limits tests were done to determine the liquid and plastic limits following the British Standards **BS 1377: Part 2 1990.**

Equipment

1. Balance
2. Casagrande's liquid limit device
3. Grooving tool
4. Mixing dishes
5. Spatula
6. Oven

Test Procedure

Approximately 250 g of air-dried soil was placed through a #40 sieve into an evaporating dish. Using a plastic squeeze bottle, enough water was added and we cranked at various revolutions per second until the two soils were united on either side. After that, we cleaned the cap after each of the at least three trials we conducted with values ranging from N-15 to 40. After 24 hours (W3), we calculated the matching w% and plotted the N vs. w%, or "flow curve."

The water concentration at which soil transitions from a liquid to a plastic form is known as the liquid limit or upper plastic limit. The apparatus was then rotated at a rate of two revolutions per minute. The liquid limit was determined. It is the lowest moisture content at which very little shear force causes a soil to flow. A cone penetrometer or the Casagrande cup method can be used to determine the liquid limit .

When a thread of soil is carefully drawn out to a diameter of 3 mm, the water content at which it simply disintegrates is known as the Plastic Limit. It is the amount of water in a soil that causes it to transition from a plastic to a semisolid condition. An ellipsoidal-sized soil mass was repeatedly rolled by hand on a non-porous surface to conduct the plastic limit

If the soil crumbled at a diameter less than 3 mm, it was wetter than the plastic limit, and vice versa.

Plasticity index is the plastic limit taken from the liquid limit and is key in soil classification.

Plasticity Index, PI = LL – PL…………………………………………..(Equation 3-1)

The water content at which the soil transitions from a semi-solid to a solid condition is known as the shrinkage limit (SL). This entails filling the empty areas caused by shrinkage with mercury after oven-drying a soil. Mercury's known density is used to compute the shrinkage volume drop. The volume of the soil mass doesn't change when the material dries more at this moisture content.

Shrinkage Limit, SL = Vs/Vw where Vs is the volume of solid particles and Vw is the volume of water. ………………………..(Equation 3-2)

Liquidity Index , LI = $\frac{W - PL}{LL - PL}$ where W is natural water content of the soil……(Equation 3-3)

Table 3-2 : Plasticity Index Results Interpretation

Plasticity Index (PI)	**Soil Type**	**Suitability for bricks**
PI less than 7%	Low plasticity	Poor cohesion, weaker bricks, reinforcements required
PI between 10% and 25%	Moderate plasticity	Optimum for brickmaking
PI more than 25%	High Plasticity	Soil is too clayey, High shrinkage and crack formation during curing

3.2.3 NATURAL MOISTURE CONTENT TEST

Natural moisture content test was done to quantify percentage of water compared to soil following British Standards **BS 812 :103.1- 1990**

Equipment

1. Oven
2. Weighing balance

Test Procedure

The experiment initiated with cleaning and drying the container to a constant weight, and this is designated W1. Next, the specimen in a container was weighed, which is designated W2, and the container was put in an oven for 24 hours. Afterward, the specimen was dried to attain a constant weight, maintaining a temperature of 105°C to 115°C for 24 hours, and the weight of the container with the dried soil sample was noted as W3. The procedure was based on the removal of moisture from soil samples by oven drying until constant weight. Moisture content (%) was expressed in terms of sample weight before and after drying.

Given

Weight of container W_1 (g)

Weight of container + wet soil W_2 (g)

Weight of container + dry soil W_3 (g)

Then Natural Moisture Content

$W(\%) = ((W_2 - W_3)/(W_3 - W_1)) * 100$……………………………………(Equation 3-4)

Table 3-3: Natural Moisture Content Specifications

Natural Moisture Content	Soil Condition	Effect on brick Performance
Less than 5%	Very Dry Soil	The bricks will be non cohesive and brittle.
5% to 10%	Slightly dry soil	Bricks are slightly cohesive and good for use
10% to 20%	Moderately dry soils	The soils are moldable and good for construction with moderate plasticity
20% to 35%	High moisture content soils	Soils are sticky and plastic and are difficult to compact
More than 35%	Extremely high Moisture content soils	Soils are close to the plastic limited workability

3.3 COMPRESSIVE STRENGTH AND WATER ABSORPTION

The compressive strength and water absorption tests were done on the raw earth bricks and those with steel fibers incorporated according to the British Standards **BS EN 771-1:2003**.

3.3.1 THE COMPRESSIVE STRENGTH TEST

Equipment

1. Unconfined compression testing machine (triaxial machine)
2. Specimen preparation equipment
3. Sample extruder
4. Balance

Test Procedure

A sample of bricks was selected averaging about five bricks and their top and bottom surfaces cleared flat to ensure that load was uniformly distributed during the Compressive Strength Test.

Then based on dimensions of the brick, area subjected to load was calculated based on those dimensions which included length, width and heights. Then bricks were subjected to uniformed and constant rate loads by a compressive strength testing machine .

From that machine, maximum load at which brick failed was read and calculated compressive strength. This procedure was then repeated in each sample brick to get average compressive strength value.

The compressive strength was calculated using the formula below

$\boldsymbol{Compresssive\ strength} = \frac{\boldsymbol{Maximum\ Load}}{\boldsymbol{Brick\ Area}}$..................**(Equation 3-5)**

3.3.2 THE WATER ABSORPTION TEST

Equipment

1. Water bath with temperatures at about 27 degrees Celsius for 24 hours
2. Weighing balance capable of weighing within 0.1% of the mass of the specimen.
3. Oven

Procedure

Water absorption test was performed purposely to determine the amount of water absorbed by the brick upon immersion in water. A selective sample of bricks was preferably dried for minimum 24 hours in an enclosed environment to remove all internal moisture from the bricks.

Once drying was done, the bricks were allowed to cool at room temperature, and each brick was measured to determine dry weight (W1). The bricks were left submerged in clean water at room temperature for 24 hours, efficiently simulating water to be absorbed by them normally.

When the period of 24 hours expired, the bricks were withdrawn from the water and wiped with a damp cloth to cleanse the surface of water. The bricks were then weighed anew to get the wet weight (W2) and the water absorption percentage was computed as below.

$$\boldsymbol{water\ absorption} = \frac{\boldsymbol{W2 - W1}}{\boldsymbol{W1}} \text{..............................}\textbf{(Equation 3-6)}$$

This value was multiplied by 100 to get its expression as a percentage and for all the tested bricks, the results were averaged to get a final value for the water absorption.

3.4 OPTIMUM STEEL FIBRE CONTENT

3.4.1 OPTIMUM STEEL FIBRE AMOUNT

The main purpose of this objective was to determine the optimal steel fiber amount which when added into the bricks gives the most balanced compressive strength and water absorption. It gave basis for the minimum steel fiber amount required to enhance the structural properties of the brick. The Optimum steel fibre content was found to be 8%.

The steel fibers were incorporated into the brick matrix at varying percentages which included but not limited to 4%, 6% and 8% after which a series of tests for compressive strength and water absorption were performed on these sampled bricks. The fiber content percentage was by brick weight based on how much of the steel fibers are contributing to the overall brick weight.

Optimization analysis was carried out using software such as excel graphs for results analysis and determination of optimal fiber content that will have been used in the various design mixes. In addition, a control group of unfired earth bricks and fired bricks without steel fibers served as a baseline for comparison.

3.4.2 THE SOUNDNESS TEST

The Soundness test of bricks showed the nature of bricks against sudden impact. In this test, 2 bricks were picked randomly and struck with one another. Then sound produced was a clear bell ringing sound and bricks did not break. Thus qualifying to be Impact resistant bricks.

3.4.3 THE EFFLORESCENCE TEST

In this test, we took a representative sample of 5 bricks and placed the end of the bricks in a dish with 25 mm depth of distilled water.

The whole arrangement was placed in a warm (20-30 °C) and well ventilated room until all the water was absorbed and evaporated.

The bricks were compared with a control sample that was not immersed.

There was no formation of a powdery, white material on the bricks, this indicated absence of efflorescence.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter outlines the experimental procedures and evaluates the findings from tests conducted on soils to be used for the unfired earth bricks, tests on the unfired earth bricks to ascertain their performance before and after reinforcement with various percentages of steel fibres, for example Particle size determination, Atterberg limits test, water absorption ,Compressive strength test among others. From Preliminary tests done on the unfired earth bricks from Bugonya village, The compressive strength was found to be 1.54 N/mm^2, which is much lower than the standard for bricks in heavy loading masonry applications of 10 N/mm^2 hence being the reason why this research needed to be carried out.

4.2 SIEVE ANALYSIS TEST

Table 4-4: Particle size distribution results

Sieve size (mm)	Weight Retained (g)	Retained (%)	Passing (%)
63.0	0.0	0	100
37.5	0.0	0.0	100
20.0	0.0	0.0	100
5.0	2.9	0.1	100
2.00	13.6	0.6	99

0.425	92.6	3.9	95
0.075	142.8	6.1	89
Total fines	2105.7	89.3	
Bottom Pan	2.5		
Extracted fines	2103.2		
Total sample	2357.6		
Grading Modulus		0.16	

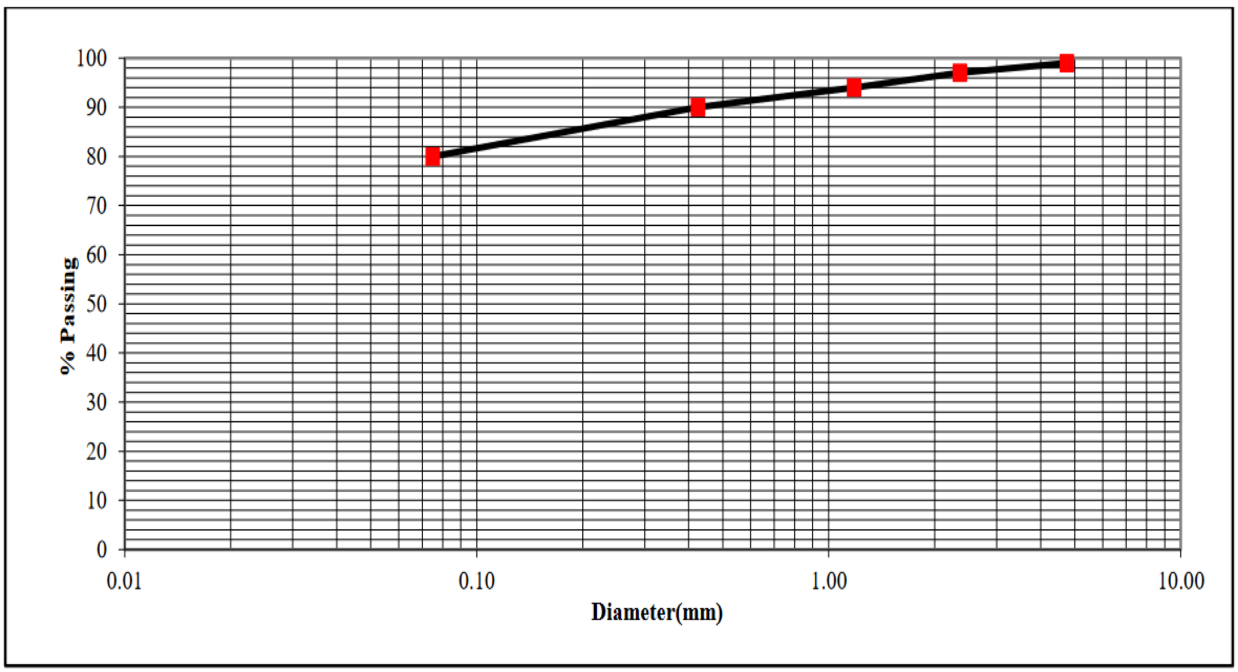

Figure 7: Particle Size Distribution Chart

The test was carried out to ascertain the particle size distribution of the soils. The test classified the soils; whether the soil comprises mainly sand, gravel, clay or silt particles. The particle size distribution is as shown above.

The soil sample was made up of a mix of fine to medium particles, with sizes between 0.075mm and 6.3mm . Majority of the sample's particles are finer, as shown by the high cumulative passing percentages for smaller sieve sizes. Predominance of finer particles such as clay or silt is key in brick making as it improves the bonding properties between particles. A composition of clayey-silt is observed . This helps the brick gain shape and be easily moulded due to plasticity on top of binding components within the brick.

The soils are poorly graded and have a narrow range of particle sizes due to a grading modulus of 0.16 lacking stability and prone to erosion and settling. Hence the need for stabilization.

4.3 USCS CLASSIFICATION CHART

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

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

Figure 8: USCS classification Chart (California Department of Transportation (Caltrans))

4.3.1 GRAIN SIZE DISTRIBUTION ANALYSIS

80% of the soil passes through the 0.075 mm sieve, which means that it is a fine-grained soil.

According to the USCS, soils that have more than 50% passing through the 0.075 mm sieve are classified as fine-grained soils (silts or clays).

Plasticity Analysis:

Liquid Limit (LL) = 56.6%

Plasticity Index (PI) = 30.0%

According to the USCS classification:

If LL > 50%, the soil is classified as high plasticity.

A PI of 30% confirms that the soil exhibits high plasticity, meaning it undergoes significant volume changes with moisture variation.

The USCS Plasticity Chart is provided below along with the test results, we can visually and logically confirm the soil classification.

LL = 56.6 on the x-axis of the chart.

PI = 30 on the y-axis.

Having Plotted the point (56.6, 30) on the graph.

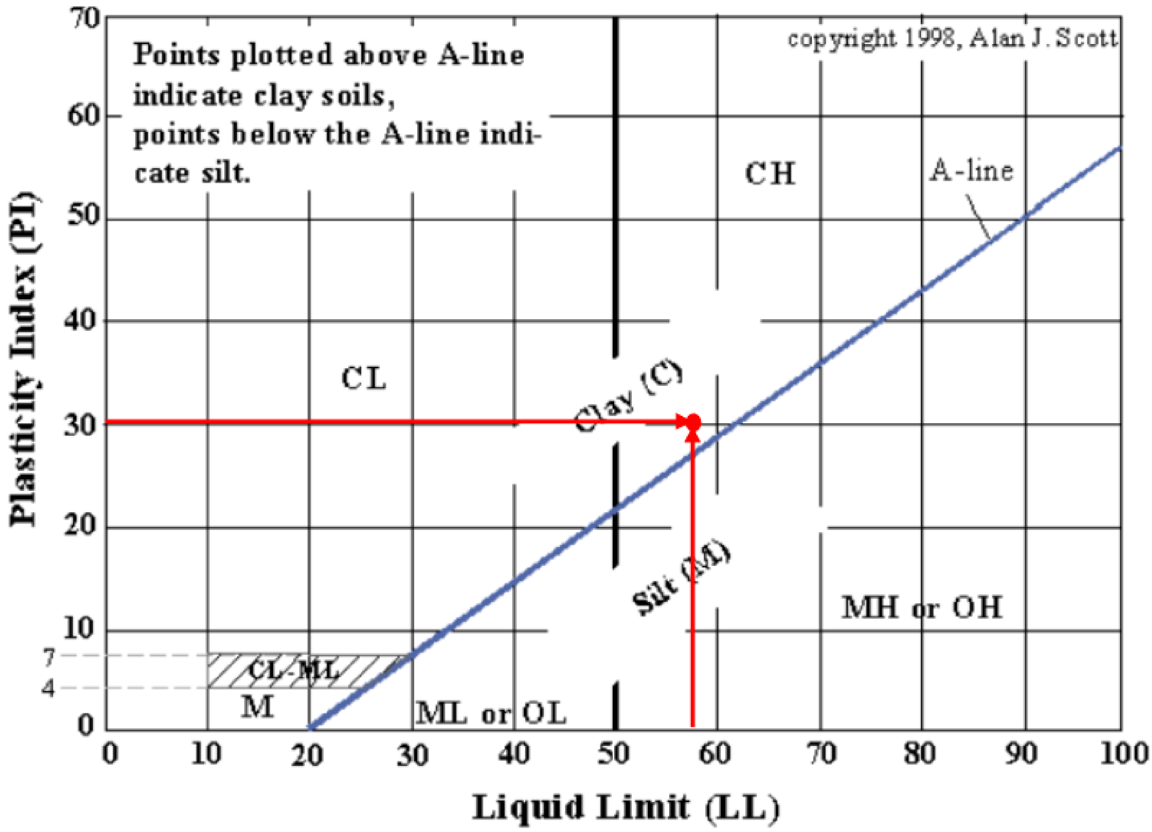

Figure 9: Plasticity Chart for USCS

From the chart:

The plotted point lies above the A-line.

It is located in the CH zone, which stands for Clay of High Plasticity

4.4 MAXIMUM DRY DENSITY

Maximum Dry Density refers to the dry density of a soil when it is compacted to its highest possible density with a definite amount of force, at its optimum moisture content. [Eko. M, 2023]

We did this test to assess the soil's ability to support loads without excessive deformation . This would be key to our compressive strength results when used to make the bricks. From our results , we had a maximum dry density of 1.557 g/cm3 which falls in the range of 1.4g/cm3 and 1.8g/cm3 that is detailed for general uses of earth in construction such as embankments and earthfills. This means our soil is quite ideal for load bearing masonry applications.

4.5 OPTIMUM MOISTURE CONTENT

Is the moisture content at which a soil is compacted to its maximum dry density. [Lachheb. M, 2021]

From our Graphs, the soils had a high optimum moisture content of 25.5 compared to the standards for silt-clayey soils of 15% to 25% which renders it easily compressible and with a reduced load bearing capacity and susceptible to destruction during drying shrinkage hence signalling the need to improve the water absorption properties.

The amount of water required for mixing during the unfired earth bricks production should be the optimum moisture content.

Although the steel fibre addition was independent of the optimum moisture content, the samples with steel had a higher dry density.

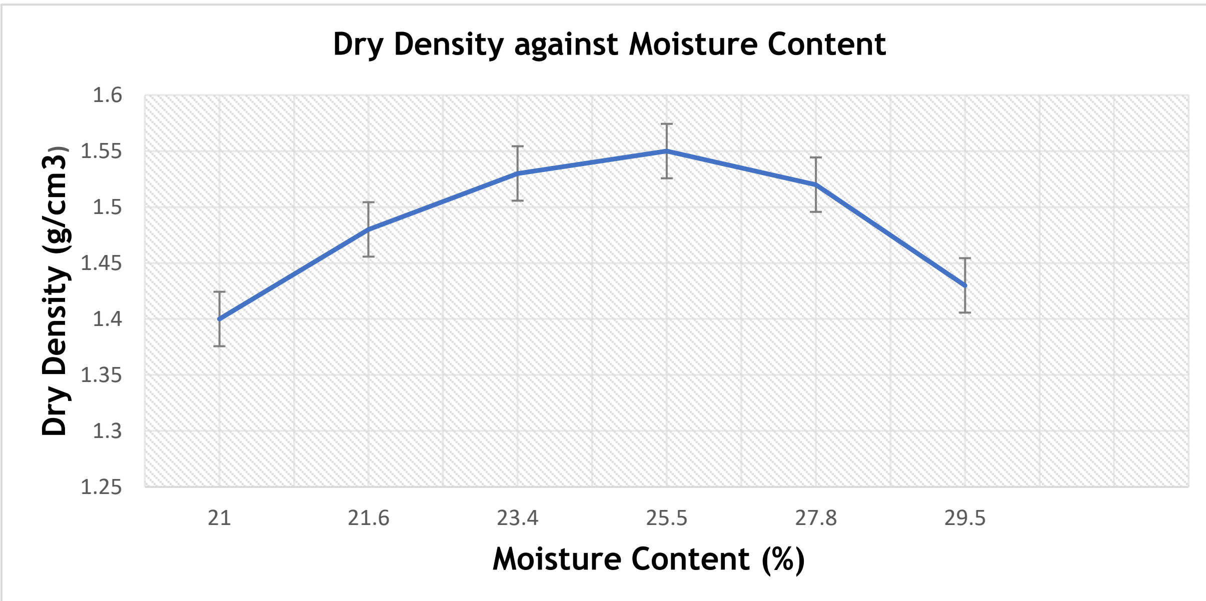

Figure 10 : A graph of Dry Density Against Moisture Content

4.6 ATTERBERG LIMITS

4.6.1 LIQUID LIMIT

Is the water content at which the soil changes from a plastic state to a liquid state. [I. Shah, 2023]

From our Lab work. Our soils had a high liquid limit of 56.6 which is way above 30 to 50 for normal plasticity soils. This may be attributed to smaller particles and higher surface areas that enable high water retention.

This high plasticity causes deformation when exposed to loads and high swelling potential, hence need for stabilization in water absorption properties

Our plasticity index of 30 is much higher than the recommended plasticity index of <20 hence high plasticity and proneness to disintegration hence a need for stabilization.. The shrinkage limit obtained is the water content at which a soil doesn't continue to change in volume as it continues to dry. From the graph, our shrinkage limit of 13.5 was also higher than normal shrinkage values of 10% signaling a need for stabilization.

The soils were determined to be high plasticity clay soil which may have contributed to its superior performance. In the modified earth blocks, the clay content serves as a binding agent which joins the bigger particles of the soil with the fibres together to ensure a strong binding effect thus leading to better performance.

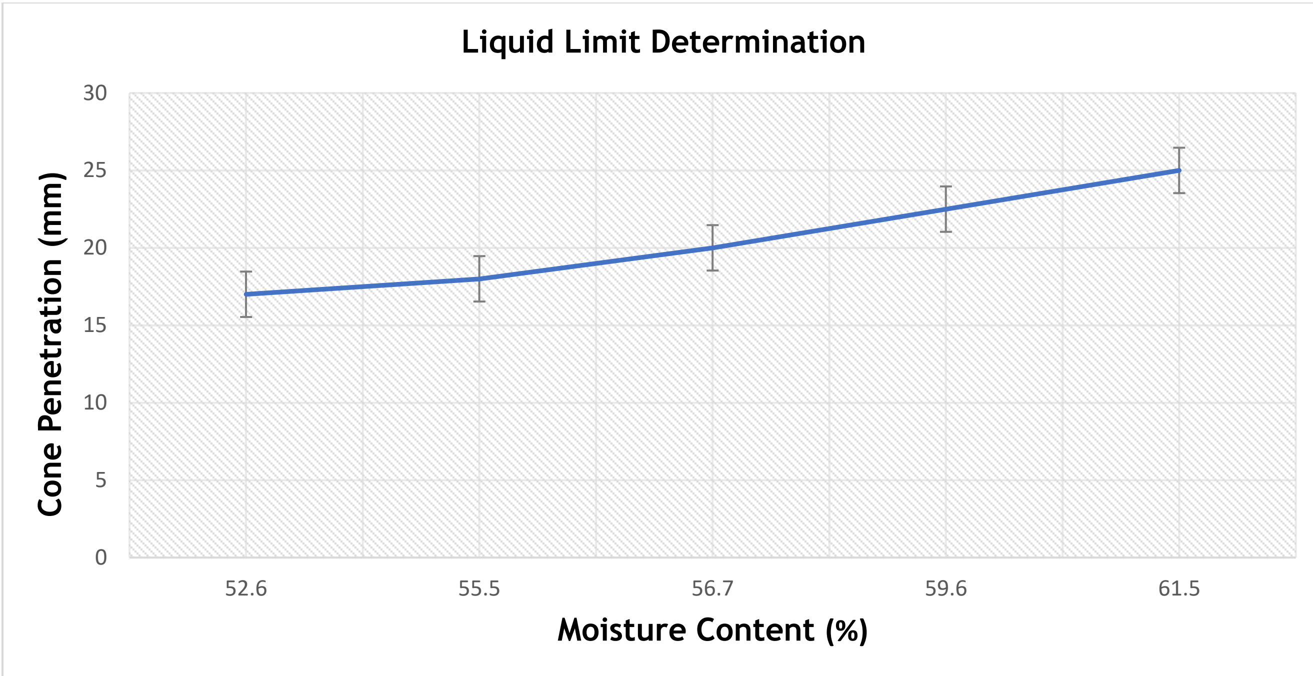

Figure 11: A graph for Liquid Limit Determination

Figure 12: Reinforced Unfired Earth Bricks Curing

4.7 COMPRESSIVE STRENGTH

Table 4-5: Compressive Strength At 7 Days

% of Steel fibres in the mix	Average weight (g)	Dimensions (mm)	Density (kg/m3)	Average Load (kN)	Compressive Strength (MPa)
0	2790	200x100x90	1.5505	27.5	1.4
4	2791	200x100x902	1.550	25	1.3
6	2748	200x100x90	1.526	31	1.6
8	2883	200x100x90	1.602	37.5	1.9

Table 4-6: Compressive Strength at 28 days

% of steel fibres in the mix	Average Weight (g)	Dimensions (mm)	Density (kg/m3)	Average Load (KN)	Compressive Strength (MPa)
0	2775	200x100x90	1.5505	33	1.7
4	2780	200x100x90	1.550	37	1.9

6	2735	200x100x90	1.526	42	2.1
8	2834	200x100x90	1.602	51	2.5

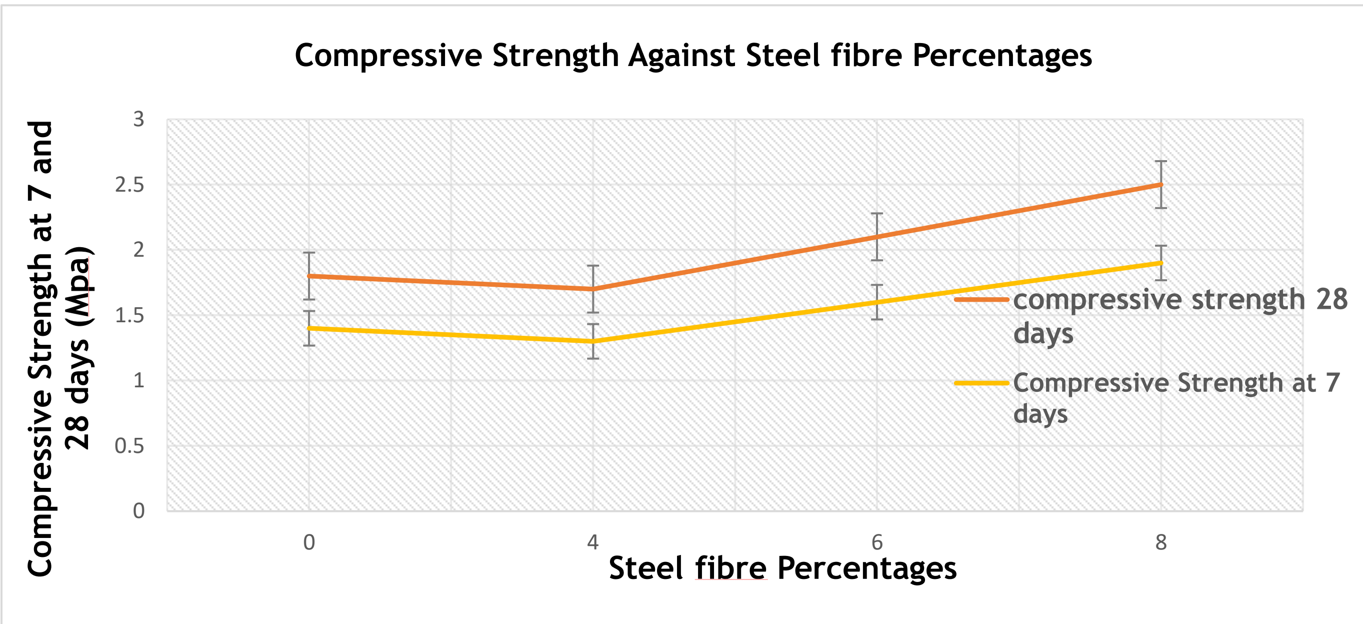

Figure 13: Compressive Strength Against Steel Fibre Percentages

4.7.1 Reason for the trend of the curves.

The initial decrease in compressive strength of the bricks from 0% to 4% was due to the initial disruption of the soil matrix properties such as cohesion.

The significant increase in compressive strength at 6% and at 8% steel fibre concentration can be attributed to the effect of steel fibres on the material's microstructure. The steel fibres act as springs and absorb a great deal of plastic energy. [Shantanu. P, 2022].

They also resist deformation without full disintegration hence increasing the compressive strength. The high aspect ratio (8:1) of steel fibres contributes to the formation of a strong and stable network of interlocking particles in the material, leading to an increase in compressive strength.

The term "aspect ratio" refers to the ratio of an object's length to its width or thickness.

In the case of steel fibres, a high aspect ratio means that the fibres have a long, thin shape, with a much greater length than its width or thickness. [Sanya. T, 2021]

Steel fibres with 8% steel fibres showcased the highest compressive strength after 28 days.

Fibres shorter than critical length induce tensile strength below fibre tensile strength. The critical length in this case was 5mm. The effect of steel fibres on the soil matrix may not be fully achieved until cracking has occurred. Ductility of the brick increases in all directions because of fibre distribution.

4.8 WATER ABSORPTION

Table 4-7: Water Absorption at 28 Days

Steel Fibre %	Average Dry Weight (mg)	Average Wet Weight (mg)	Water Absorption Rate (%)
0	2724	4175.5	14.5
4	2740	3965	12.3
6	2818	3984	11.7
8	2918	3874	9.6

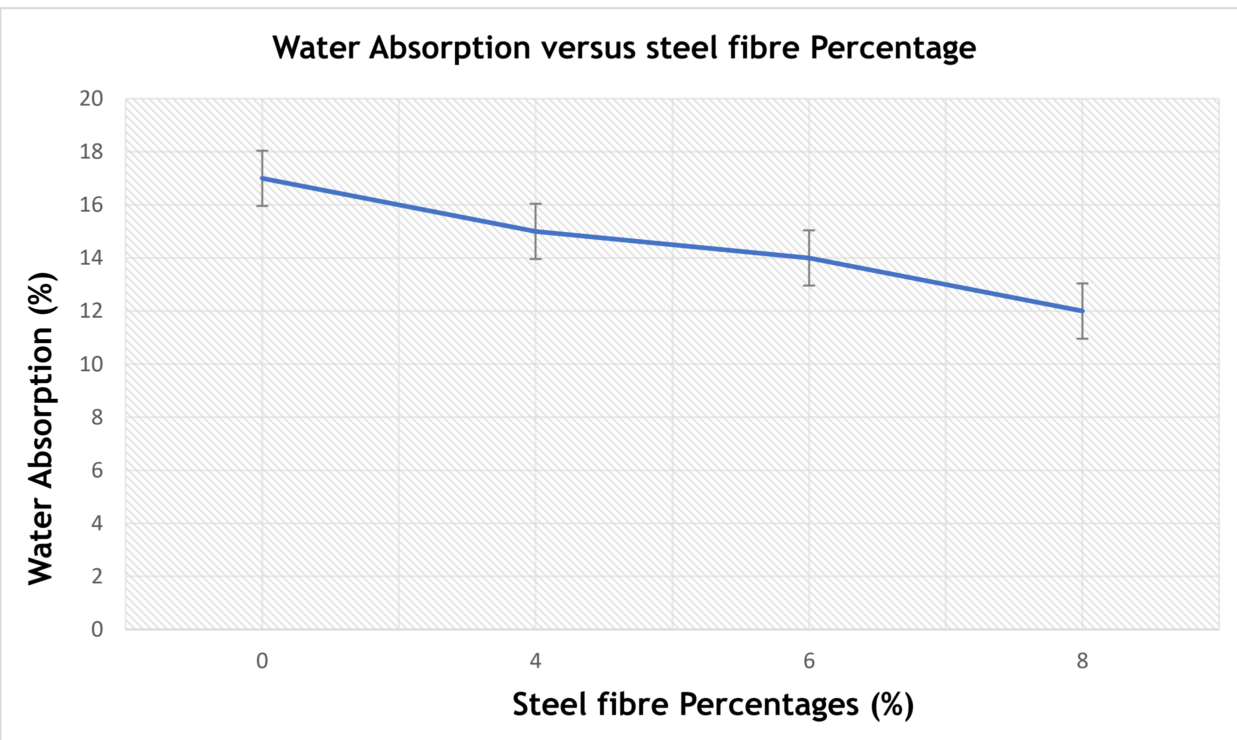

Figure 14: Water absorption against steel fibre Percentages

4.8.1 Reason for the trend of the curves

The water absorption of the brick reducesd with increase in steel fibre percentage from 0% to 4% to 6% to 8% respectively as the fibres are hydrophobic and do not absorb water easily. Steel fibres also bridge the cracks and fill voids that would accommodate water in the soil matrix.

The addition of steel fibers increased the cohesion among soil particles, hence averting water absorption from the unification of particles that would then fill up the voids capable of holding moisture. According to Coutts and Ni 2022, they explained that the percentage of water absorbed by fiber-modified soil matrices depends on void volume and affects density. Hence, it follows that with an increase in the fiber content, one would expect higher density and less water absorption on account of the high specific weight of the recycled steel fibers.

Once again, water absorption influences the environmental sensitivity of fibre-reinforced composites with respect to their performance and service life. In the case of the composites containing a matrix and reinforcing fibres, both will undergo dimensional changes and deterioration of mechanical properties due to environmental behavior in humid climates.

The amount of moisture that enters the composite depends on the presence of the matrix and type of fibres, volume fraction of fibres, temperature, and relative humidity. For this reason, we chose to use a synthetic fibre as unfired earth bricks are especially susceptible to moisture penetration through the plant-based fibres than with synthetic fibres. Plant fibres that are hydrophilic with hydroxyl groups provide effective interaction with water molecules. For example, authors reported that the moisture absorption of jute fibre-reinforced polyester is from 5% to 14% when kept at 23°C for 24 hours. In turn, the fibres swell to a greater degree, weakening the fibre-matrix interface and reducing mechanical characteristics, owing to incredibly high moisture absorption.. (Munimathan et al., 2024). This phenomenon can validate our choice of a synthetic fibre vis a vis a natural fibre for brick reinforcement.

Table 4-8: Quality Control and Assurance

Test	Required Standards	Obtained Results	Remarks
Particle size Distribution	A grading Modulus of 1.5 or more.	Low grading Modulus of 0.16	Soils are prone to erosion and disintegration hence a need for stabilisation
Maximum Dry Density	1.4g/cm3 to 1.8g/cm3	1.557g/cm3	Soils are barely ideal for load bearing masonry applications.
Optimum Moisture Content	Liquid Limit – 30% to 50%	56.6%	There is a need to improve the water absorption properties of the soils.

	Plasticity index – Should be less than 20% Shrinkage Limit – Should be less than 10%	30% 13%	There is a need for stabilization of the soils. There is a need for Stabilisation of the soils.
Compressive strength	2.0 N/mm2 for unfired earth bricks	1.4 N/mm2 for the neat brick	There is a need for stabilization to buffer the compressive strength properties of the bricks.
Water Absorption test	Should be less than 12%	14.5% for the neat bricks	There is a need for stablisation to improve the water absorption properties.
Soundness test	A sharp metallic sound should be heard on clapping two bricks together.	A distinct, metallic ringing sound was heard.	The bricks are well resistant to sudden impact.
Efflorescence test	Absence of powdery residues on evaporation.	A white, powdery residue not observed after evaporation.	This signals absence of soluble salts in the brick structure.

4.9 MIX DESIGN

Unfired earth bricks comprise of various constituents such as silica(50%), alumina(20% to 30%), lime (5% to 10%), iron oxide (5% to 7%) and magnesia(1%) according to literature. (Berhampur, 2021). Our samples were reinforced with steel fibres at percentages of 4%, 6% and 8%.

Table 4-9: Weight in kgs needed for a single block

Steel fiber Percentage	**Material**	**Weight (g)**
4	Earth	2860
6		2670
8		2545
Total		**8075**
4	Steel Fibers	300
6		450
8		600
Total		**1350**

Table 4-10: The different mass in grams needed to make a brick with different percentages of steel fibres added

Steel fibres (%)	Mass of Earth (g)
0	3000
4	2860
6	2670
8	2545

Various tests are done as curing takes place including at 7 days and at 28 days.

Number of bricks needed = (number of samples x number of tests to be conducted x % of steel fibres) = (3x4x4) = 48 bricks (only 7 days)

Total bricks for all different curing days (7 days, 28 days) = (48x2) = 96 bricks

Therefore 96 bricks needed for the whole project

Therefore 48 blocks are needed to be made at curing of 7 days

Amount of materials needed at curing days (7 days)

Total mass of steel fibres needed = (number of samples x number of tests x total mass of total steel fibre weight) =(3x4x1350) = 16.2 kg

Total mass of earth = (3x4x 8075) = 96kg

Total amount of materials required for the project

Total mass of steel fibres needed = (16.2kg x2)= **32.4kg**

Total mass of earth needed = (96x2) = **192 kg**

- **Using the optimum of 8%,** an appropriate ratio for mix by weight is **1kg of steel fibres: 6kg of earth: 1.6 litres of water** in the brick manufacture**.**

4.10 COST BENEFIT ANALYSIS

Volume of 1 brick = (0.200 x 0.150 x 0.090)

= 0. 0027m3

For 1000 bricks = 2.7 m3

Cost of the Steel fibres= 3500/= per uncut steel fibre ring

1 ring of uncut steel fibres can reinforce 30 bricks at 8% Percentage by weight

For 1000 bricks = 1000/30= 33.333

33.333 x 3500 = 116,666/= for 2.7 m3 of bricks

Weight of 1000 bricks approx. = 3,000kg

Labor = 25,000/= per 1000 bricks

Total cost for 1000 bricks = 116,000+ 25,000

= 141,000/=

Cost per reinforced brick = 141,000/=/1000

Cost per reinforced brick ≈ 141/=

VS

Cost per traditional burnt brick ≈ 250/

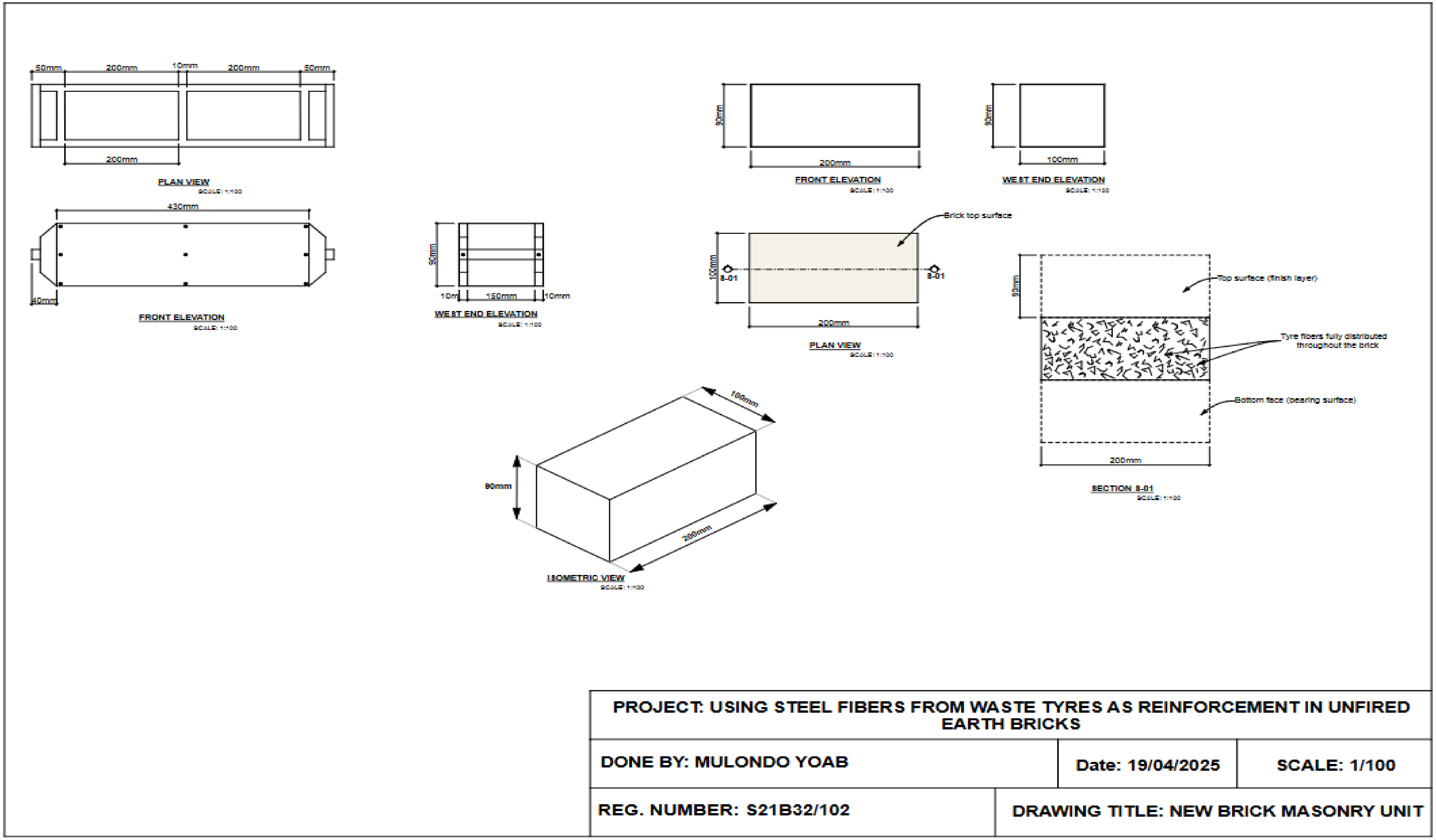

Figure 15: Design drawings for the reinforced earth bricks

4.11 PROJECT LOGICAL FLOW

USING STEEL FIBRES FROM WASTE TYRES AS REINFORCEMENTS IN AN UNFIRED EARTH BRICK

PRELIMINARY STUDY; PROBLEM STATEMENT, OBJECTIVES

Determine the physical and Mechanical properties of the soil to be used for the earth bricks.

Determine the effect of steel fibres on the compressive strength and water absorption properties of the unfired earth bricks

Determine the optimum steel fibre percentage for reinforcement in the Unfired Earth Bricks

Optimum steel fibre Percentage for reinforcement determined as 8% of total brick weight for both compressive strength and water absorption properties.The bricks were found to pass the soundness and efflorescence tests

Physical and Mechanical Properties Analysis

1. Particle size distribution test
2. Atterberg limits test
3. Proctor Compaction Test (Maximum dry density and Optimum Moisture Content)
4. Natural Moisture Content Test

For every steel fibre reinforcement percentage, Compressive strength and water absorption tests were taken after 7 and 28 days.

Figure 16: A Flowchart depicting the Project's Logical flow

CHAPTER FIVE: CHALLENGES, CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

5.1.1 PARTICLESIZE DISTRIBUTION AND ATTERBERG LIMITS

5.1.2 PARTICLE SIZE DISTRIBUTION

From the Particle size distribution test, the soil sample was made up of a mix of fine to medium particles, with sizes between 0.075mm and 6.3mm . Majority of the sample's particles are finer, as shown by the high cumulative passing percentages for smaller sieve sizes. Predominance of finer particles such as clay or silt is key in brick making as it improves the bonding properties between particles. A composition of clayey-silt is observed . This helps the brick gain shape and be easily moulded due to plasticity on top of binding components within the brick.

Conversely, The soils are poorly graded and have a narrow range of particle sizes due to a grading modulus of 0.16 lacking stability and prone to erosion and settling. Hence the need for stabilization.

5.1.3 MAXIMUM DRY DENSITY.

From our results, we had a maximum dry density of 1.557 g/cm3 which falls in the range of 1.4g/cm3 and 1.8g/cm3 that is detailed for general uses of earth in construction such as embankments and earthfills. This means our soil is barely ideal for load bearing masonry applications.

5.1.4 OPTIMUM MOISTURE CONTENT

From our Graphs, the soils had a high optimum moisture content of 25.5 compared to the standards for silt-clayey soils of 15% to 25% which renders it easily compressible and with a reduced load bearing capacity and susceptible to destruction during drying shrinkage hence signalling the need to improve the water absorption properties.

The amount of water required for mixing during the unfired earth bricks production should be the optimum moisture content.

Although the steel fibre addition was independent of the optimum moisture content, the samples with steel had a higher dry density.

5.1.5 ATTERBERG LIMITS

5.1.5.1 LIQUID LIMIT

From our Lab work. Our soils had a high liquid limit of 56.6 which is way above 30 to 50 for normal plasticity soils. This may be attributed to smaller particles and higher surface areas that enable high water retention.

This high plasticity causes deformation when exposed to loads and high swelling potential, hence need for stabilization in water absorption properties

5.1.5.2 PLASTICITY INDEX

Our plasticity index of 30 is much higher than the recommended plasticity index of <20 hence high plasticity and proneness to disintegration hence a need for stabilization. The shrinkage limit obtained is the water content at which a soil doesn't continue to change in volume as it continues to dry. From the graph, our shrinkage limit of 13.5 was also higher than normal shrinkage values of 10% signaling a need for stabilization.

The soils were determined to be high plasticity clay soil which may have contributed to its superior performance. In the modified earth blocks, the clay content serves as a binding agent which joins the bigger particles of the soil with the fibres together to ensure a strong binding effect thus leading to better performance.

5.1.6 COMPRESSIVE STRENGTH

The significant increase in compressive strength at 6% and at 8% steel fibre concentration can be attributed to the effect of steel fibres on the material's microstructure. The steel fibres act as springs and absorb a great deal of plastic energy. [Shantanu. P, 2022].

Steel fibres with 8% steel fibres showcased the highest compressive strength after 28 days. Fibres shorter than critical length induce tensile strength below fibre tensile strength. Our critical length was 5mm in this case. The effect of steel fibres on the soil matrix may not be fully achieved until cracking has occurred. Ductility of the brick increases in all directions because of fibre distribution.

5.2 WATER ABSORPTION PROPERTIES

The water absorption of the brick reduced with increase in steel fibre percentage from 0% to 4% to 6% to 8% respectively as the fibres are hydrophobic and do not absorb water easily.

This was explained by [Coutts and Ni ,2022] who stated that the percentage of water absorbed by fiber modified soil matrices depended on their void volume and has an effect on density. Thus, one would expect the density to increase and the water absorption to decrease as the fibre content is increased, due to the high specific weight of the reinforcing steel fibres.

Soundness tests were also done and a distinct, metallic ringing sound was heard hence the bricks resist well sudden impact.

Efflorescence test was also done and a white, powdery residue was not observed on the bricks after evaporation hence absence of soluble salts in the brick structure

5.3 CHALLENGES

1. The Steel rings had to be shredded out of the tyre structure by a special machine called a Bead Extractor and whereby the laboratories didn't have the machine so we had to incur extra expenses by looking for a company with such a machine.
2. The challenge of finding distilled water for the efflorescence tests whereby the laboratory (Stirling) didn't have the distilled water and apparatus so we had to pay to another laboratory with the apparatus thus more expenses.

5.4 RECOMMENDATIONS

1 There should be a pilot study on the application of bricks stabilized with steel fibres at 8% weight percent.

2 Long term studies on the durability of reinforced bricks under various environmental conditions e.g droughts

3 Life-Cycle cost analysis should be done done to compare the use of steel fibre reinforcement with conventional brick production methods.

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APPENDIX A :MATERIALS AND MATERIALS TESTING IN THE LABORATORY

Fig 1 :Section depicting uncut steel fibre rings from the tyres

Fig 2: Steel fibre rings after cutting to 5mm lengths

Fig 3 :The Compressive Strength Machine

Fig 4: Homogenous mixing of wet soil with steel fibres

Fig 5: Material preparation by breaking soil lumps to fine Particles

Fig 6: Rammer used during brick Production

Fig 7: Freshly cut 5mm Steel fibres being prepared for casting

5Fig

Fig 8: 5mm cut steel fibre Preparation for use in the Brick

Fig 9: Cast bricks during the Air Drying Process

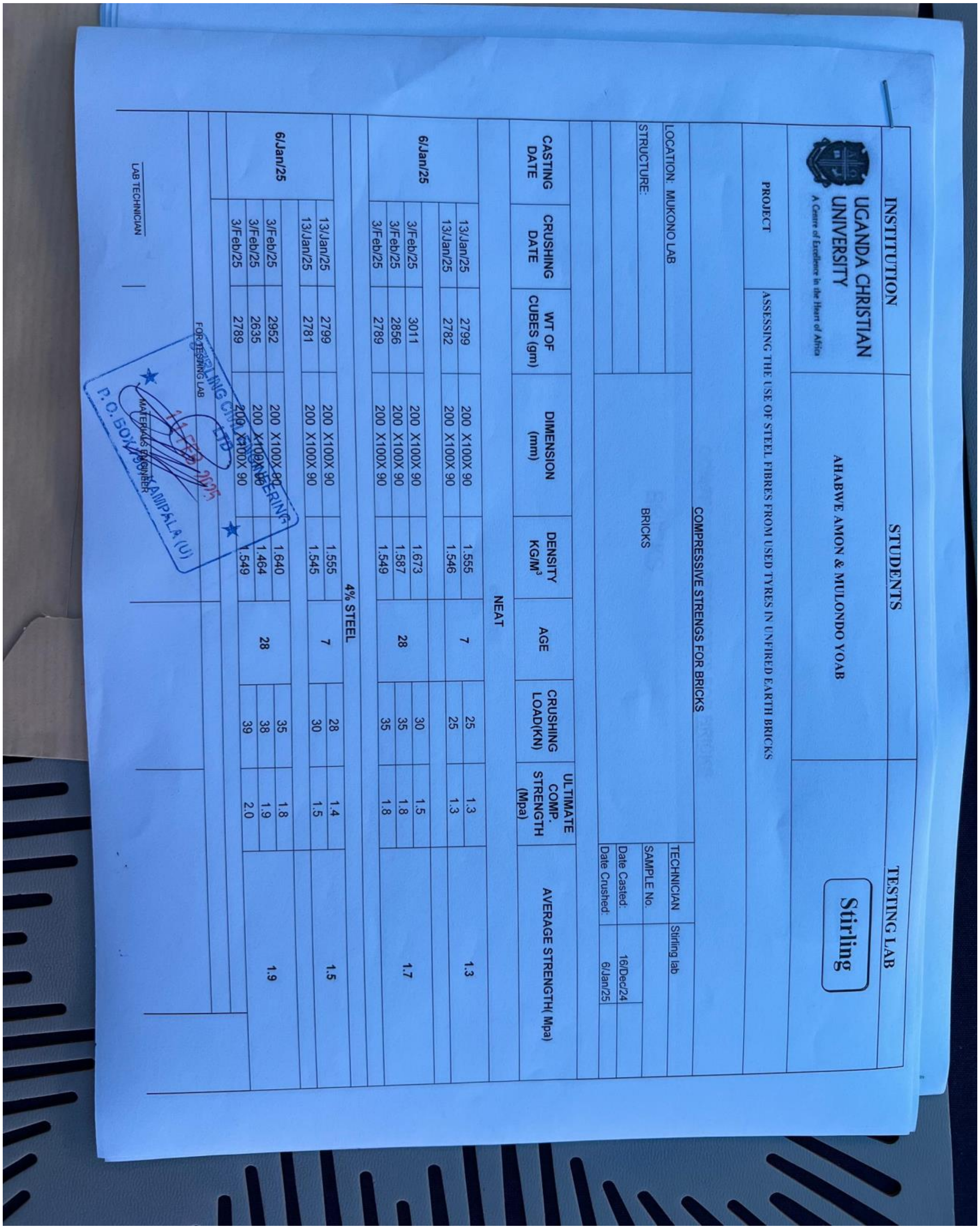
Fig 10: Measuring a soil sample before mixing and molding

Fig 11: The grinder used for cutting the steel fibres to 5mm

Fig 12:The brick making process

Fig 13: The steel fibres and earth before mixing

APPENDIX B : LABORATORY RESULTS



INSTITUTION: UGANDA CHRISTIAN UNIVERSITY — A Centre of Excellence in the Heart of Africa

STUDENTS: AHABWE AMON & MULONDO YOAB

TESTING LAB: Stirling

PROJECT: ASSESSING THE USE OF STEEL FIBRES FROM USED TYRES IN UNFIRED EARTH BRICKS

COMPRESSIVE STRENGS FOR BRICKS

LOCATION: MUKONO LAB

STRUCTURE: BRICKS

TECHNICIAN: Stirling lab

SAMPLE No.:

Date Casted: 16/Dec/24

Date Crushed: 6/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)
NEAT								
6/Jan/25	13/Jan/25	2799	200 X100X 90	1.555	7	25	1.3	1.3
	13/Jan/25	2782	200 X100X 90	1.546		25	1.3	
	3/Feb/25	3011	200 X100X 90	1.673	28	30	1.5	1.7
	3/Feb/25	2856	200 X100X 90	1.587		35	1.8	
	3/Feb/25	2789	200 X100X 90	1.549		35	1.8	
4% STEEL								
6/Jan/25	13/Jan/25	2799	200 X100X 90	1.555	7	28	1.4	1.5
	13/Jan/25	2781	200 X100X 90	1.545		30	1.5	
	3/Feb/25	2952	200 X100X 90	1.640	28	35	1.8	1.9
	3/Feb/25	2635	200 X100X 90	1.464		38	1.9	
	3/Feb/25	2789	200 X100X 90	1.549		39	2.0	

LAB TECHNICIAN

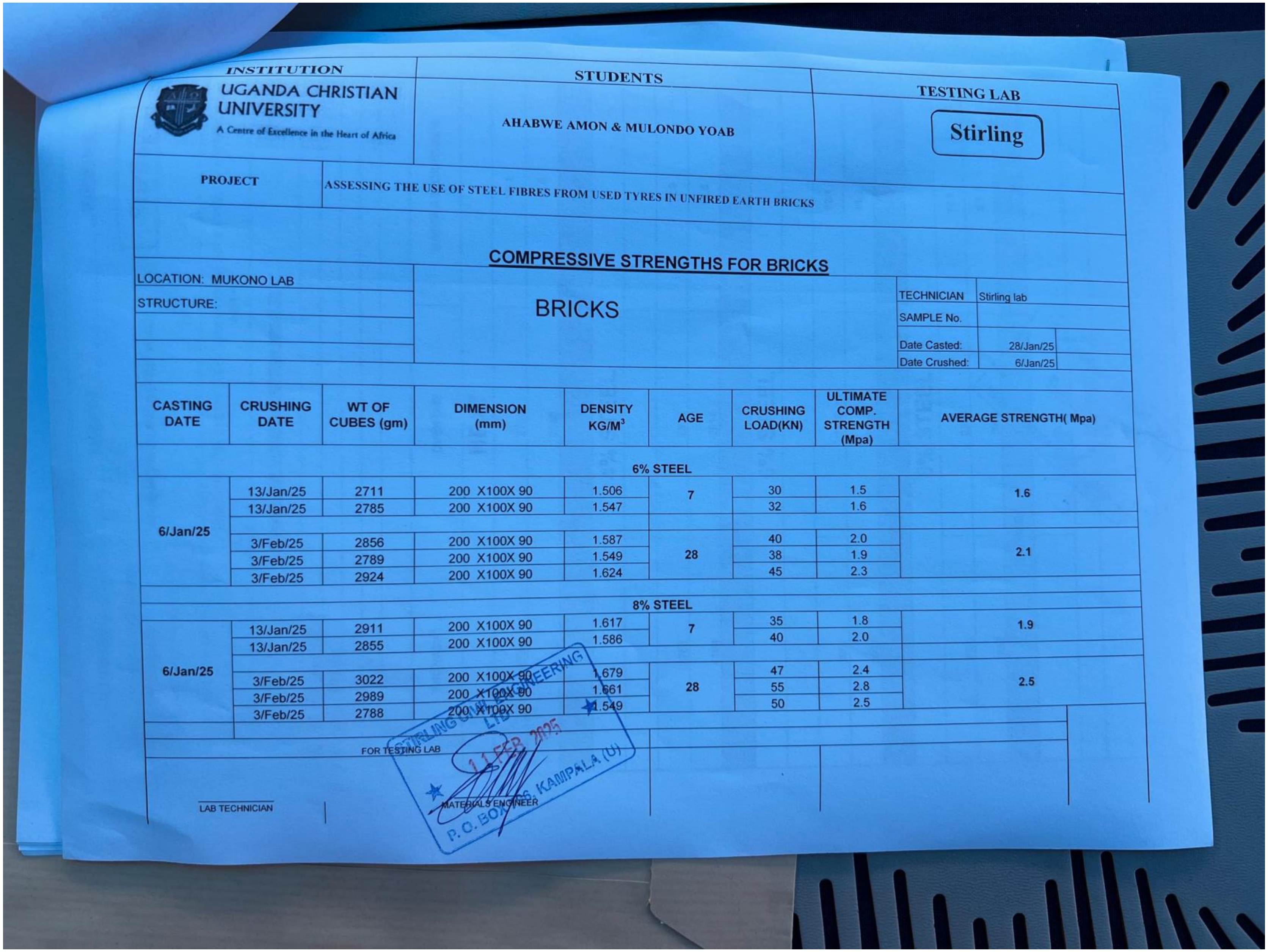
FOR TESTING LAB

STIRLING CIVIL ENGINEERING LTD

11 FEB 2025

MATERIALS ENGINEER

P.O. BOX [illegible] KAMPALA (U)



INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AHABWE AMON & MULONDO YOAB	Stirling

PROJECT: ASSESSING THE USE OF STEEL FIBRES FROM USED TYRES IN UNFIRED EARTH BRICKS

COMPRESSIVE STRENGTHS FOR BRICKS

LOCATION: MUKONO LAB

STRUCTURE:

BRICKS

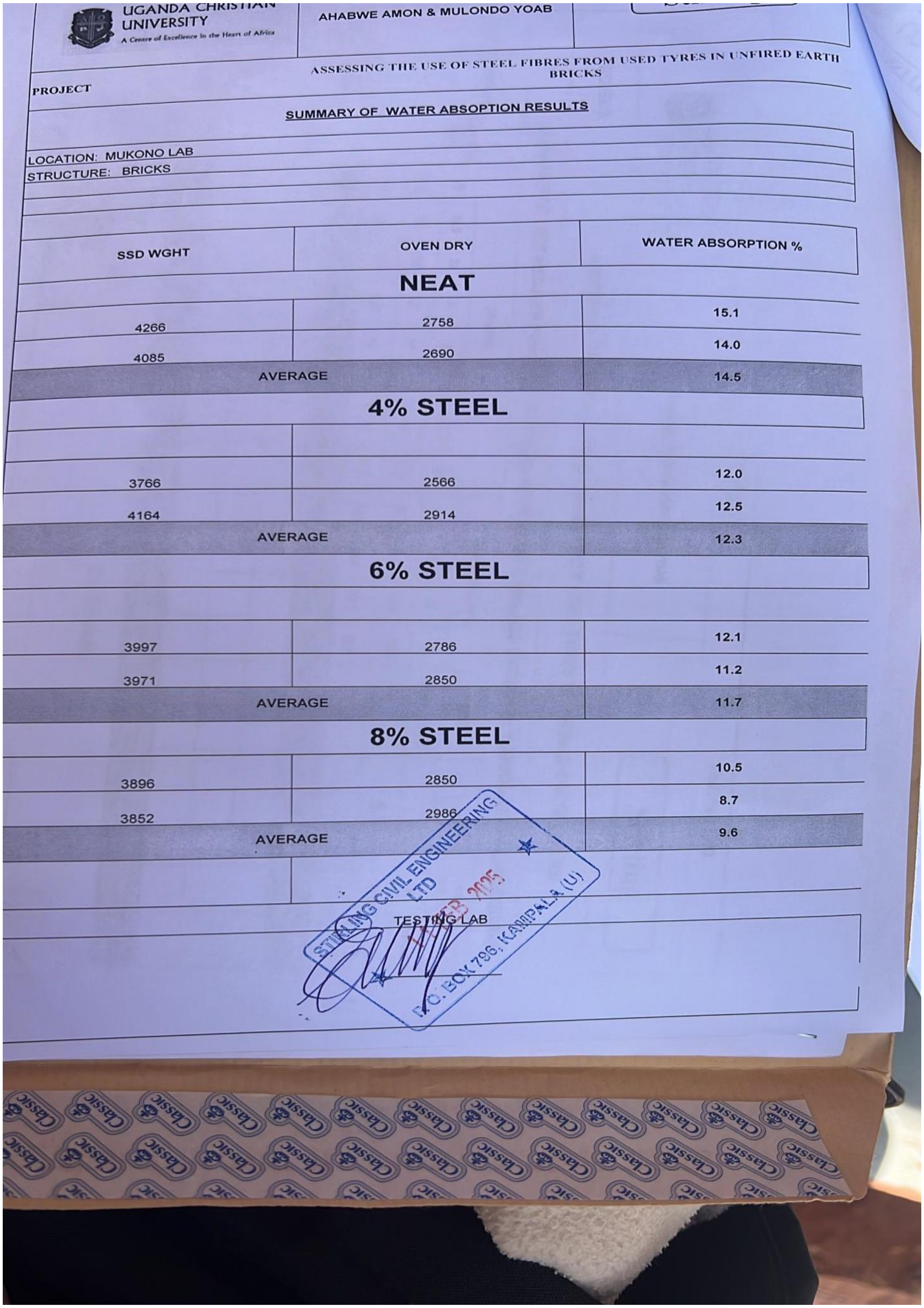
TECHNICIAN	Stirling lab
SAMPLE No.	
Date Casted:	28/Jan/25
Date Crushed:	6/Jan/25

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)
6% STEEL								
6/Jan/25	13/Jan/25	2711	200 X100X 90	1.506	7	30	1.5	1.6
	13/Jan/25	2785	200 X100X 90	1.547		32	1.6	
	3/Feb/25	2856	200 X100X 90	1.587	28	40	2.0	2.1
	3/Feb/25	2789	200 X100X 90	1.549		38	1.9	
	3/Feb/25	2924	200 X100X 90	1.624		45	2.3	
8% STEEL								
6/Jan/25	13/Jan/25	2911	200 X100X 90	1.617	7	35	1.8	1.9
	13/Jan/25	2855	200 X100X 90	1.586		40	2.0	
	3/Feb/25	3022	200 X100X 90	1.679	28	47	2.4	2.5
	3/Feb/25	2989	200 X100X 90	1.661		55	2.8	
	3/Feb/25	2788	200 X100X 90	1.549		50	2.5	

FOR TESTING LAB

LAB TECHNICIAN

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



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PROJECT: ASSESSING THE USE OF STEEL FIBRES FROM USED TYRES IN UNFIRED EARTH BRICKS

SUMMARY OF WATER ABSOPTION RESULTS

LOCATION: MUKONO LAB
STRUCTURE: BRICKS

SSD WGHT	OVEN DRY	WATER ABSORPTION %
NEAT		
4266	2758	15.1
4085	2690	14.0
AVERAGE		14.5
4% STEEL		
3766	2566	12.0
4164	2914	12.5
AVERAGE		12.3
6% STEEL		
3997	2786	12.1
3971	2850	11.2
AVERAGE		11.7
8% STEEL		
3896	2850	10.5
3852	2986	8.7
AVERAGE		9.6

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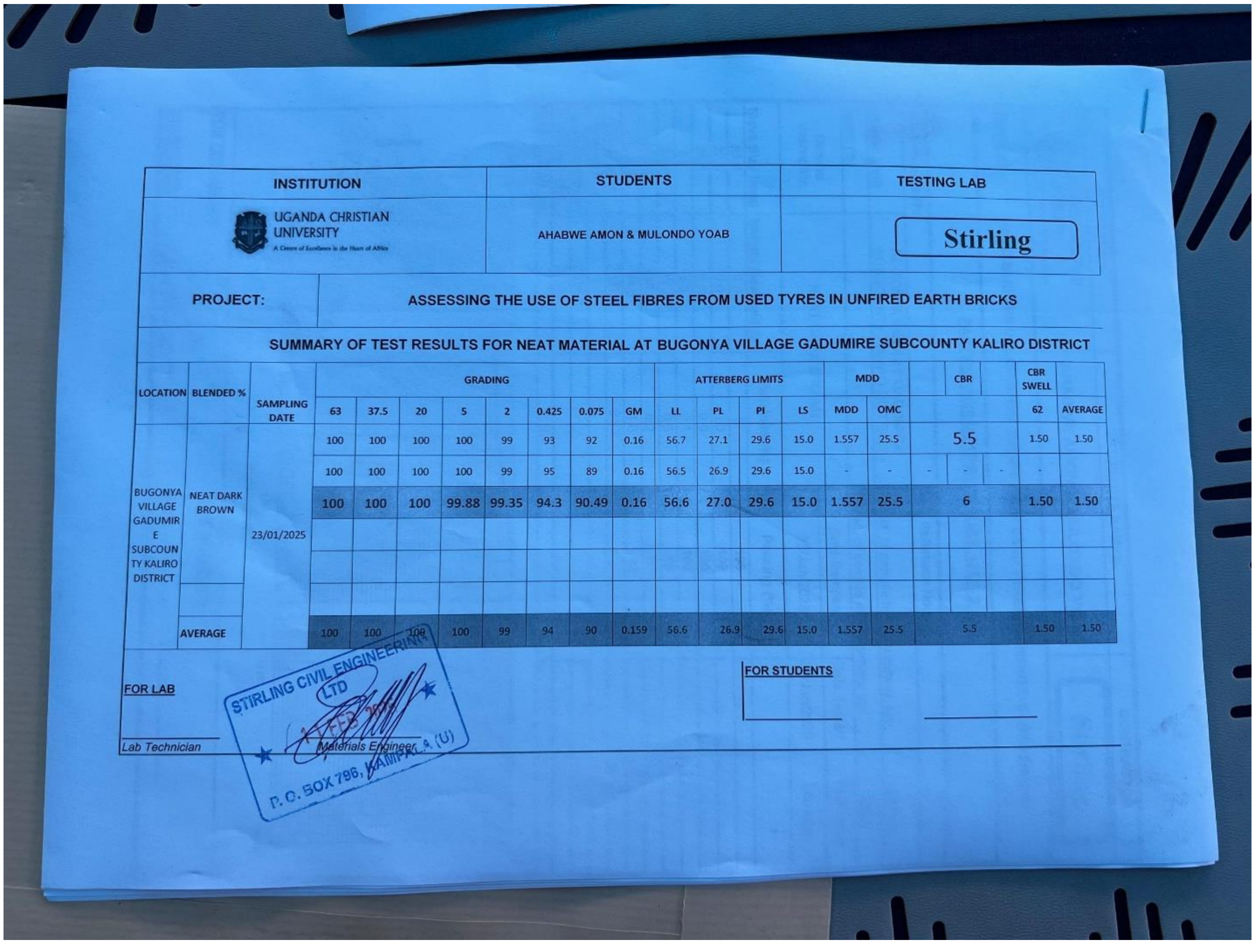
TESTING LAB
P.O. BOX 796, KAMPALA (U)
FEB 2025



INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AHABWE AMON & MULONDO YOAB	Stirling

PROJECT: ASSESSING THE USE OF STEEL FIBRES FROM USED TYRES IN UNFIRED EARTH BRICKS

SUMMARY OF TEST RESULTS FOR NEAT MATERIAL AT BUGONYA VILLAGE GADUMIRE SUBCOUNTY KALIRO DISTRICT

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTERBERG LIMITS				MDD			CBR		CBR SWELL	
			63	37.5	20	5	2	0.425	0.075	GM	LL	PL	PI	LS	MDD	OMC				62	AVERAGE
BUGONYA VILLAGE GADUMIRE SUBCOUNTY KALIRO DISTRICT	NEAT DARK BROWN	23/01/2025	100	100	100	100	99	93	92	0.16	56.7	27.1	29.6	15.0	1.557	25.5		5.5		1.50	1.50
			100	100	100	100	99	95	89	0.16	56.5	26.9	29.6	15.0	-	-	-	-	-	-	
			100	100	100	99.88	99.35	94.3	90.49	0.16	56.6	27.0	29.6	15.0	1.557	25.5		6		1.50	1.50
	AVERAGE		100	100	100	100	99	94	90	0.159	56.6	26.9	29.6	15.0	1.557	25.5		5.5		1.50	1.50

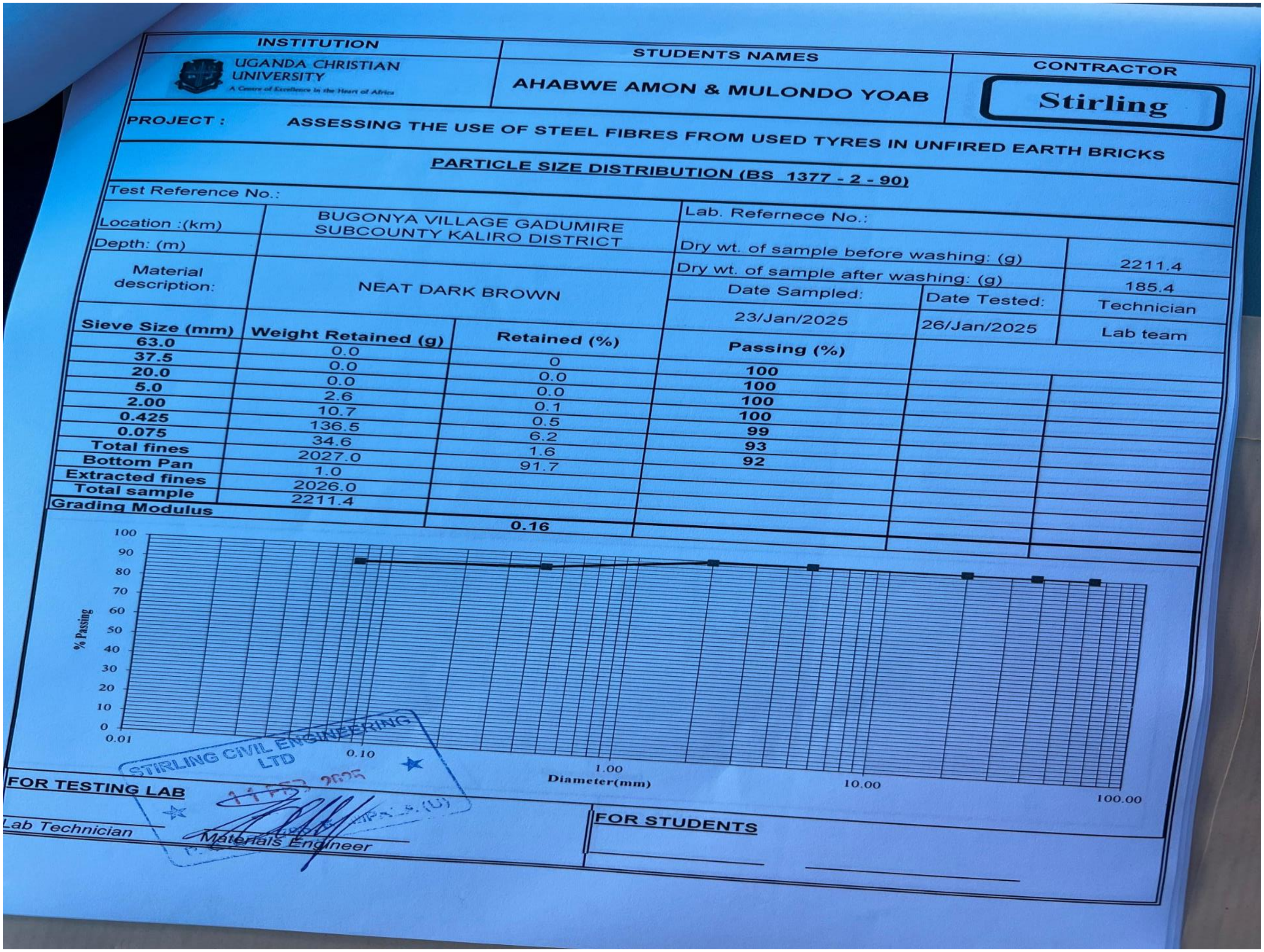
FOR LAB

Lab Technician

Materials Engineer

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

FOR STUDENTS



INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AHABWE AMON & MULONDO YOAB	Stirling

PROJECT : ASSESSING THE USE OF STEEL FIBRES FROM USED TYRES IN UNFIRED EARTH BRICKS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:				
Location :(km)	BUGONYA VILLAGE GADUMIRE SUBCOUNTY KALIRO DISTRICT	Lab. Refernece No.:		
Depth: (m)		Dry wt. of sample before washing: (g)		2211.4
Material description:	NEAT DARK BROWN	Dry wt. of sample after washing: (g)		185.4
		Date Sampled:	Date Tested:	Technician
		23/Jan/2025	26/Jan/2025	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)
63.0	0.0		
37.5	0.0	0	100
20.0	0.0	0.0	100
5.0	2.6	0.0	100
2.00	10.7	0.1	100
0.425	136.5	0.5	99
0.075	34.6	6.2	93
Total fines	2027.0	1.6	92
Bottom Pan	1.0	91.7	
Extracted fines	2026.0		
Total sample	2211.4		
Grading Modulus		0.16	

% Passing

Diameter(mm)

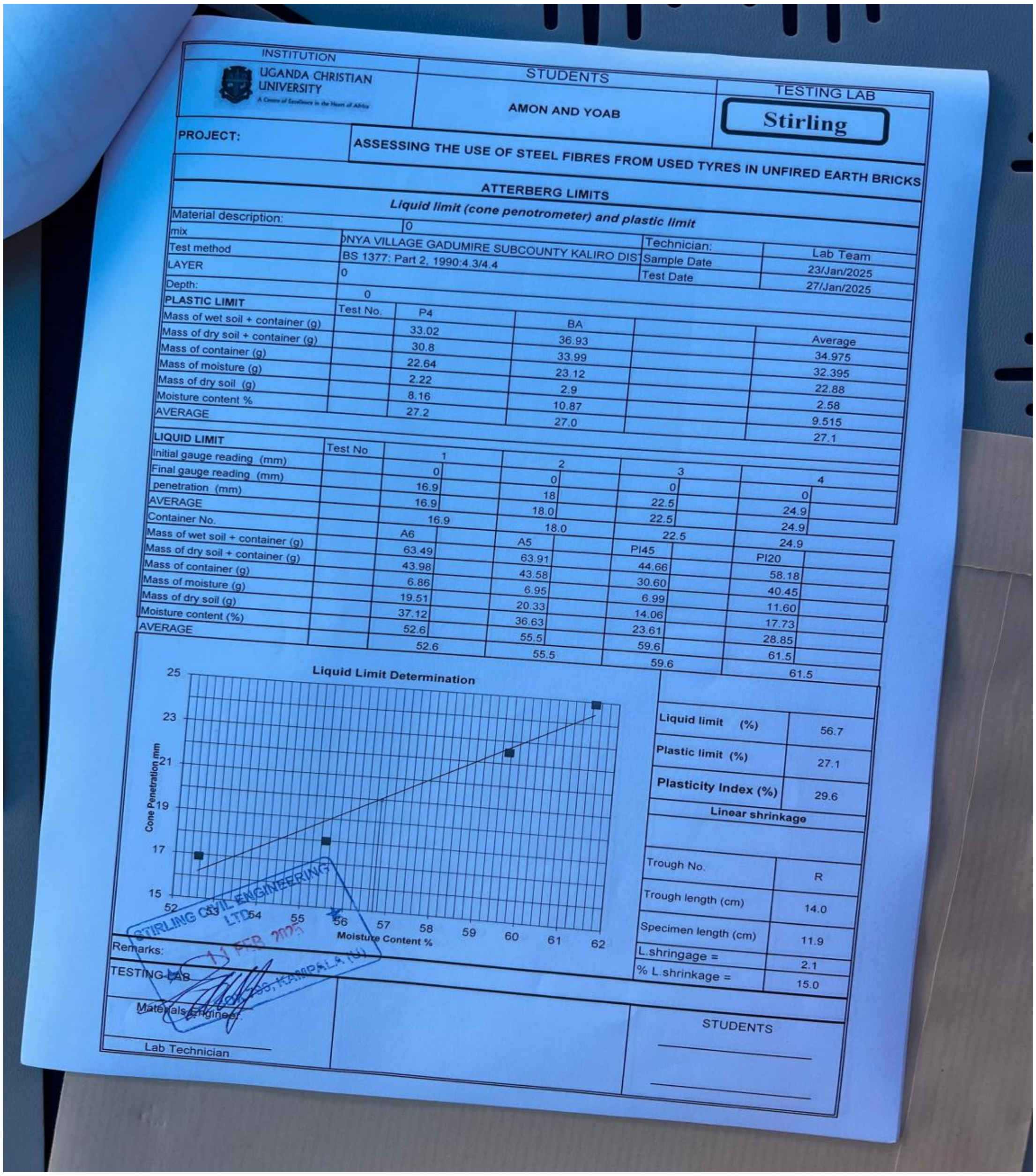
FOR TESTING LAB

STIRLING CIVIL ENGINEERING LTD

Lab Technician

Materials Engineer

FOR STUDENTS



INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AMON AND YOAB	Stirling

PROJECT: ASSESSING THE USE OF STEEL FIBRES FROM USED TYRES IN UNFIRED EARTH BRICKS

ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Material description:	0		
mix			
Test method	ONYA VILLAGE GADUMIRE SUBCOUNTY KALIRO DIS	Technician:	Lab Team
LAYER	BS 1377: Part 2, 1990:4.3/4.4	Sample Date	23/Jan/2025
Depth:	0	Test Date	27/Jan/2025
	0		

PLASTIC LIMIT	Test No.	P4	BA		
Mass of wet soil + container (g)		33.02	36.93		Average
Mass of dry soil + container (g)		30.8	33.99		34.975
Mass of container (g)		22.64	23.12		32.395
Mass of moisture (g)		2.22	2.9		22.88
Mass of dry soil (g)		8.16	10.87		2.58
Moisture content %		27.2	27.0		9.515
AVERAGE					27.1

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		16.9	18	22.5	24.9
penetration (mm)		16.9	18.0	22.5	24.9
AVERAGE		16.9	18.0	22.5	24.9
Container No.		A6	A5	PI45	PI20
Mass of wet soil + container (g)		63.49	63.91	44.66	58.18
Mass of dry soil + container (g)		43.98	43.58	30.60	40.45
Mass of container (g)		6.86	6.95	6.99	11.60
Mass of moisture (g)		19.51	20.33	14.06	17.73
Mass of dry soil (g)		37.12	36.63	23.61	28.85
Moisture content (%)		52.6	55.5	59.6	61.5
AVERAGE		52.6	55.5	59.6	61.5

Liquid limit (%)	56.7
Plastic limit (%)	27.1
Plasticity Index (%)	29.6
Linear shrinkage	
Trough No.	R
Trough length (cm)	14.0
Specimen length (cm)	11.9
L.shringage =	2.1
% L.shrinkage =	15.0

Remarks:

TESTING LAB

Materials Engineer

Lab Technician

STUDENTS

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AHABWE AMON & MULONDO YOAB	Stirling

PROJECT:	ASSESSING THE USE OF STEEL FIBRES FROM USED TYRES IN UNFIRED EARTH BRICKS			
Test Reference No.	Lab. Reference No.	Date Sampled	Date Tested	Technician
SOURCE	BUGONYA VILLAGE GADUMIRE SUBCOUNTY KALIRO DISTRICT	23/Jan/25	26/Jan/25	Lab team
Material description:	NEAT DARK BROWN	Natural moisture (%) :	11.0	

TEST DATA

Weight of rammer (Kg)	No. of blows per layer	No of layers	Height of drop (mm)	Diameter of mould(mm)	Volume of mould (cm^3)
4.5	62	5	457	152	2,260

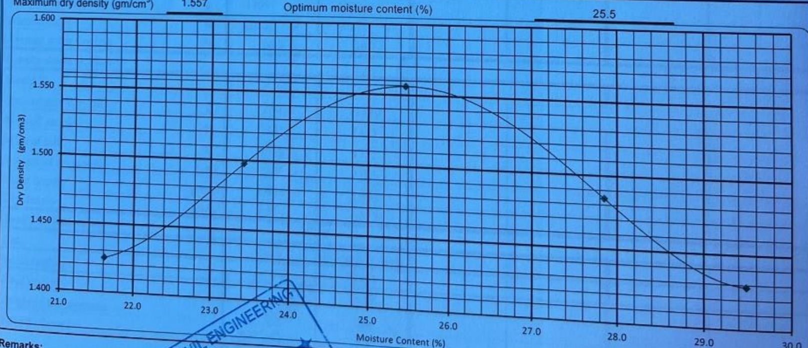
MOISTURE CONTENT DATA

Test No.		1	2	3	4	5
Tin No.		A	A	A	A	A
Water Added	cm^3	160	260	360	460	560
Mass of Compacted soil + mould	gm	8,791	9,052	9,287	9,164	9,055
Mass of Mould	gm	4,875	4,875	4,875	4,875	4,875
Mass of Compacted soil	gm	3916	4177	4412	4289	4180
Volume of mould	cm^3	2,260	2,260	2,260	2,260	2,260
Wet density of soil	g/cm^3	1.733	1.848	1.952	1.898	1.850

DATA FOR PROCTOR CURVE

Container No.		PI	HP	AT	DAD	KCR
Mass of wet soil + Container	gm	1,158.0	1,188.0	1,199.0	1,005.0	1,941.0
Mass of dry soil + container	gm	973.0	991.0	980.0	812.0	1,596.0
Mass of container	gm	117.0	150.0	120.0	119.0	426.0
Mass of water added	gm	185	197	219	193	345
Mass of dry soil	gm	856	841	860	693	1170
Moisture content	%	21.6	23.4	25.5	27.8	29.5
Dry density	g/cm^3	1.425	1.497	1.556	1.484	1.428

Maximum dry density (gm/cm^3) 1.557 Optimum moisture content (%) 25.5



Remarks:

FOR TESTING LAB		FOR STUDENTS
Lab Technician	Materials Engineer	

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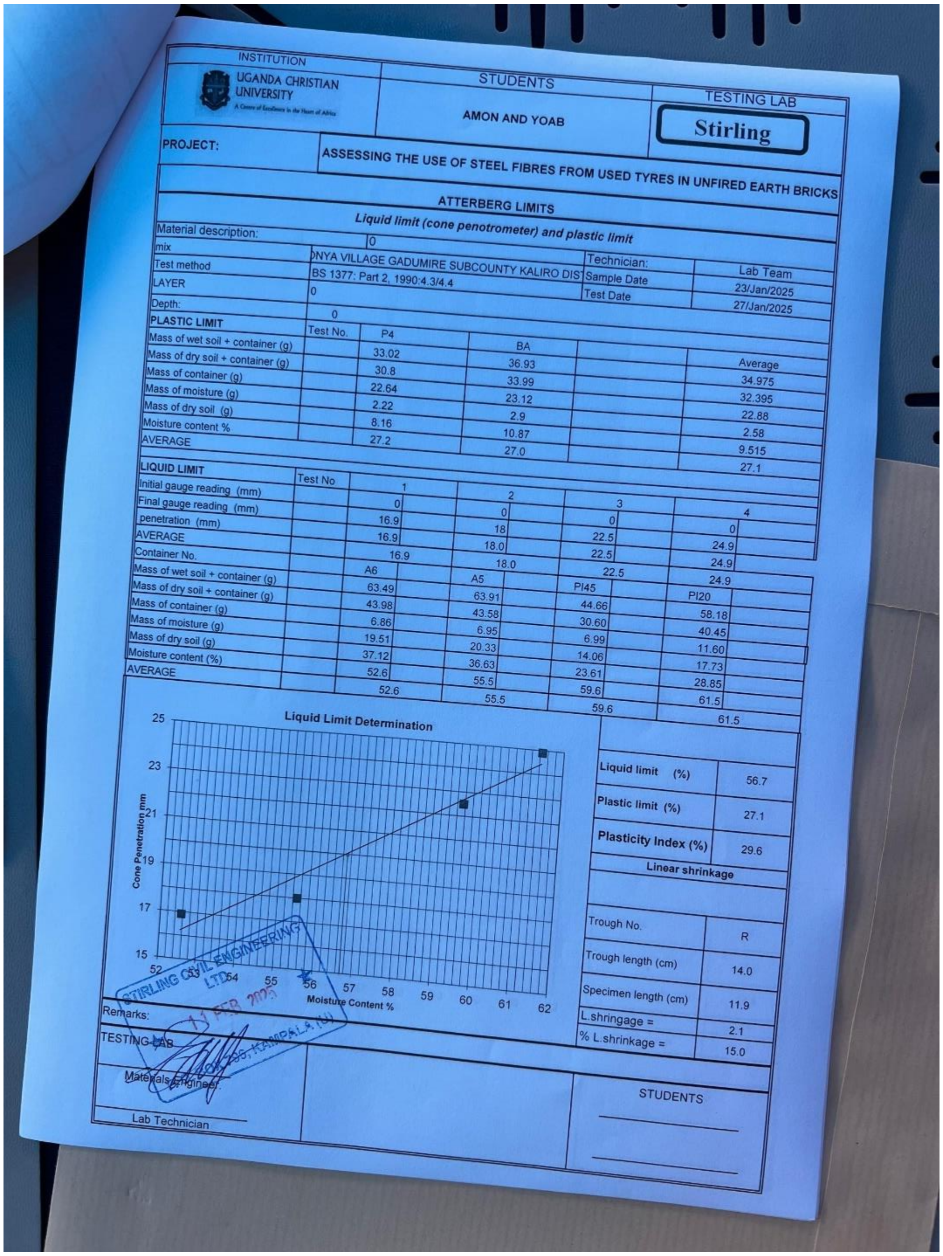
KAMPALA (U)



INSTITUTION

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

STUDENTS: AMON AND YOAB

TESTING LAB: Stirling

PROJECT: ASSESSING THE USE OF STEEL FIBRES FROM USED TYRES IN UNFIRED EARTH BRICKS

ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Material description:			
mix	0		
Test method	ONYA VILLAGE GADUMIRE SUBCOUNTY KALIRO DIST	Technician:	Lab Team
LAYER	BS 1377: Part 2, 1990:4.3/4.4	Sample Date	23/Jan/2025
Depth:	0	Test Date	27/Jan/2025
	0		

PLASTIC LIMIT	Test No.	P4	BA		Average
Mass of wet soil + container (g)		33.02	36.93		34.975
Mass of dry soil + container (g)		30.8	33.99		32.395
Mass of container (g)		22.64	23.12		22.88
Mass of moisture (g)		2.22	2.9		2.58
Mass of dry soil (g)		8.16	10.87		9.515
Moisture content %		27.2	27.0		27.1
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		16.9	18	22.5	24.9
penetration (mm)		16.9	18.0	22.5	24.9
AVERAGE		16.9	18.0	22.5	24.9
Container No.		A6	A5	PI45	PI20
Mass of wet soil + container (g)		63.49	63.91	44.66	58.18
Mass of dry soil + container (g)		43.98	43.58	30.60	40.45
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Mass of moisture (g)		19.51	20.33	14.06	17.73
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Moisture content (%)		52.6	55.5	59.6	61.5
AVERAGE		52.6	55.5	59.6	61.5

Liquid Limit Determination

Cone Penetration mm: 25, 23, 21, 19, 17, 15

Moisture Content %: 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62

Liquid limit (%)	56.7
Plastic limit (%)	27.1
Plasticity Index (%)	29.6
Linear shrinkage	
Trough No.	R
Trough length (cm)	14.0
Specimen length (cm)	11.9
L.shringage =	2.1
% L.shrinkage =	15.0

Remarks:

TESTING LAB

Materials Engineer

Lab Technician

STUDENTS

STIRLING CIVIL ENGINEERING LTD
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