ANALYSIS OF ENGINEERING PROPERTIES OF LATERITE BLOCKS REINFORCED WITH PINEAPPLE LEAF FIBRES

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TECHNOLOGY AND INNOVATION

2018

Analysis of Engineering Properties of Laterite Blocks Reinforced with Pineapple Leaf Fibres

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A Thesis Submitted to The Pan African University, Institute of Science, Technology and Innovation, In Partial Fulfilment of the Requirement for the Award of the Degree of Master of Science in Civil Engineering (Structural Engineering Option)

2018

DECLARATION

This thesis is my original work and has not been submitted to any educational institution or university for the award of a degree. Therefore, I declare that all the materials quoted in it, which are not mine have been duly acknowledged.

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DEDICATION

This work is dedicated to the almighty God.

ACKNOWLEDGEMENT

I wish to sincerely thank my supervisors Prof. Christopher KANALI and Dr. John MWERO for their supportive advice and correction of my reports. I also extend my gratitude to Pan Africa University Institute of Science Technology and Innovation (PAUISTI) for giving me the chance to study, research and for their financial support.

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LIST OF SYMBOLS AND ABBREVIATIONS/ACRONYMS

PALF	Pineapple leaf fibre
NaOH	Hydroxides of Sodium
CE	Common Era
BS	British Standard
IS	India Standard
NFC	Natural fibre composite
FAO	Food and Agriculture Organization
FRP	Fibre Reinforced Plastics
OPEFB	Oil Palm Empty Fruit Bunche
PP	Polypropylene
H_2O_2	Hydrogen Peroxide
LEDCs	Less Economically Developed Countries
SiO_2	Silicon dioxide
Al_2O_3	Aluminium Oxide
Fe_2O_3	Ferric Oxide
K_2O	Potassium Oxide
OPF	Oil Palm Fruit Fibre
CSEB	Compress stabilized earth block
OLB	Ordinary Laterite Block
LDPE	Low-Density, Polyethylene Composite
Lshr	Shrinkage length
FRC	Fibre Reinforced Concrete
NBRRI	Nigeria Building and Road Research Institute
P	the maximum load, in N

fct	the tensile splitting strength, in MPa or N/mm^2
L	the length of the line of contact of the specimen, in mm
S	Modulus of rupture of the block at the plane of failure, PSI (MPa);
W	Maximum load indicated by the testing machine, (N);
L	Span length, in mm;
d	specimen diameter in mm
t	Specimen thickness in mm
σt	The tensile splitting
d	Wide of specimen
Cs	Compressive strength
f	Flexural strength
T	Tensile splitting strength
Θ	Water absorption
α	Abrasion index
ρ	Density

ABSTRACT

This study focused on investigating the engineering properties of cement stabilized laterite soil blocks reinforced with treated pineapple leaves fibres (T-PALF) and untreated ones (N-PALF). The fibre content in the blocks ranged from 0 to 5% in proportion of 1% by weight. Three types of blocks were casted: cubical, rectangular and cylindrical. The cubical blocks measured 140*140*140 mm and were used for compression, water absorption and density analysis. The rectangular ones measured 290*140*120 mm and were used for flexural strength, abrasion and drop test assessment. The cylinder blocks measured 100 mm in diameter and 150 mm in height and were used for splitting tensile tests. The blocks were stabilized with 3 and 5% cement. The compressive strength was assessed at 7, 14, 21 and 28 days of curing but the flexural strength, splitting tensile strength, water absorption, abrasion, and drop test were conducted at 28th day of curing. Density was determined at 14, 21 and 28 days of curing. The results show that the performance of blocks reinforced with T-PALF was better than those with N-PALF. In addition, there was a significant increase of flexural strength of blocks reinforced with T-PALF. The highest compressive strength of the blocks was obtained at 28 days of curing. The corresponding values of blocks stabilized with 3 and 5% of cement reinforced with T-PALF were 4.01 and 4.81 MPa, respectively, while the one reinforced with N-PALF were 3.19 and 4.63 MPa, respectively. The results further show that the highest flexural strength of both stabilized blocks at 3 and 5% of cement reinforced with T-PALF and N-PALF were obtained with the blocks stabilized with 5% of cement reinforced with T-PALF. The high value of tensile strength has led to increase of compressive and flexural strength of the blocks. It was observed that the water absorption of the blocks increased with increase of the fibre content, but those reinforced with N-PALF absorbed more water than those reinforced with T-PALF. The cost benefit analysis shows that it is less expensive to produce soil blocks reinforced PALF as compared to commercially clay burnt bricks.

CHAPTER ONE

1. INTRODUCTION

1.1 Background to the Study

Historically, laterite was cut into block like shapes and used in monument buildings. After 1000 Current Era, construction at Angkor Wat and other South East Asian sites changed to rectangular temple enclosures made of laterite, block and stone. Since the mid-1970s, some trial sections of bituminous surfaced, low volume roads have used laterite in place of stone as a base course.

Recently, there has been a rapid growth in research and innovation in the natural fibre composite area. Interest is warranted due to the advantages of these materials compared to others, such as synthetic fibre composites, including low environmental impact and cost which render them have high potential across a wide range of applications. Much effort has gone into improving the mechanical properties of laterites to enhance their performance in order to meet the demand for their wider applications (Jaramillo et al., 2016).

Fibres are a class of hair-like material being discrete or elongated, similar to pieces of thread. These materials have been used for centuries in several processes such as clothing and in the building industry (Mohanty et al., 2005). In 2013, about 32 million tons of natural fibres were produced worldwide (Jaramillo et al., 2016). Review of literature shows that there has been a tremendous increase in research from 1985 to 2014 in the area of composites with natural fibres. Additionally, for promoting natural fibre use, 2009 was considered as international year of natural fibres and the composites market of United States recorded 2.7–2.8 billion pounds from 2006 to 2007 (Asim et al., 2015).

Natural fibres from pineapple leaves are a good option to study because of their high tensile strength and high cellulose content (Kalia and Kaith, 2011); furthermore PALF has high specific strength and stiffness it is hydrophilic in nature due to high cellulose content (Asim et al., 2015). After harvesting, utilization of pineapple waste would be an alternative and renewable source of natural fibres for building material. The use of fibre-reinforcement in construction materials can enhance structural strength and toughness, and this can reduce cracking and shrinkage (de Aro et al., 2012). With the increase of conventional construction materials costs such as sand, cement and timber, the building industry has to seek for alternative low cost materials of acceptable quality. This study explores the feasibility of using pineapple leaf fibre (PALF) as reinforcement in laterite blocks for construction of low cost buildings.

1.2 Statement of the Problem

Earth as a construction material lacks certain engineering properties, for example earth blocks suffer from shrinkage, cracking, low strength, and lack of durability (Danso et al., 2014). The improvement of these properties would enhance the use of earth as a building material. Several studies have focused on the improvement and stabilization of earth as building material to meet the required standards (Heathcote, 1991; Ren et al., 1995; Walker, 1995; Ogunye et al., 2002; Khedari et al., 2005; Achenza et al., 2006; Morel et al., 2007). Several natural fibres such as sisal fibre, jute fibre, oil palm bunch fibre, coconut fibre and so on, have already been used for reinforcement of soil blocks, however, these fibres are mostly not available in Africa. Hence, there is need to search for natural fibres that are available in Africa for use as construction material. Pineapple is fibrous and is the second most important tropical fruit in Africa after banana (Adegbite et al., 2014); therefore, it is necessary to include pineapple leaf fibre to other natural fibres as soil block reinforcement material, as it has superior quality as compared to others natural fibres.

The use and adoption of the right stabilization technology can improve the compressive strength of a soil by as much as 400 to 500% (Yalley et al., 2013). According to many studies, pineapple leaf fibre has good engineering properties in composites reinforcement. In addition, the use of natural fibres in composite reinforcement leads to reduction of the amount of cement used in soil reinforcement and this minimises environment pollution and also reduces the cost of construction. (Leão et al., 2015). If one has to meet the increasing demand for buildings there is a need for optimum utilization of available raw materials to produce environmentally friendly and sustainable building alternatives.

1.3 Objectives

1.3.1 General objective

The general objective of this study is to analyse the engineering properties of laterite blocks reinforced with pineapple leaf fibres.

1.3.2 Specific objectives

i. To assess the engineering properties of laterite soils and pineapple leaf fibres for use as construction materials for low-cost buildings;

ii. To evaluate the performance of reinforced laterite blocks with pineapple leaf fibre as construction materials for low-cost buildings;
iii. To determine the cost-benefit of using reinforced laterite blocks with pineapple leaf fibres as construction materials for low-cost buildings.

1.3.3 Research questions

i. What are the engineering properties of laterite soils and pineapple fibres for use as construction materials for low-cost buildings?
ii. How is the performance of reinforced laterite blocks with pineapple leaf fibre as construction materials for low-cost buildings?
iii. What is the cost benefit of using reinforced laterite blocks with pineapple leaf fibres as construction material for low-cost buildings?

1.4 Justification

The main aim of this study is to establish the feasibility of using pineapple leaf fibres as alternatives for soil reinforcement, and also determine the physical and mechanical properties of laterite blocks when reinforced with the fibres. In particular, the study focusses on providing durable and affordable construction material for the poor and those who are not able to make sand blocks for building, and also reduce the quantity of river sand used in construction as means of reducing river erosion. Laterite fibre reinforced blocks do not require baking, hence, can be attractive building material because they are inexpensive to make. The high cost of conventional building materials, in most cases, is due to the cost of transportation and government tax. Therefore, by enhancing the performance of local available laterite soil blocks for building purpose, many people who are scared of using them because of their poor quality can safely start using them, thereby avoiding using the expensive river sand. Finally, based on the findings by other researchers about the use of pineapple leaf fibres as good reinforcement material in concrete, and in polymer composite, the use of these fibres will improve the strength of laterite blocks.

1.5 Scope of the Study

The study focuses on the use of pineapple leaf fibres for reinforcement of laterite soil blocks. It was conducted in the Civil and Construction Engineering laboratory of Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya from the month of February to June 2018. The fibres were imported from India while the sand and cement were procured appropriately, and the laterite soil was obtained from suitable sites around JKUAT. During this study, 332 cubicle blocks of dimensions 140x140x140mm were tested for compressive strength and density; 132 blocks of dimensions 290x140x120mm were tested for flexural strength and abrasion test experiment, and 44 cylindrical blocks of diameter 100 mm and height 150 mm were tested for splitting tensile strength. Blocks with 0, 1, 2, 3, 4 and 5% of pineapple leaf fibres were compared. The engineering properties of the blocks were evaluated based on the British Standard (BS), India standard (IS), Nigeria building and road research institute (NBRRI) and New Zealand Standard (NZS).

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Theoretical Review

2.1.1 Types of natural and synthetic fibres

The two different types of fibres that are used in composites include natural and synthetic or man-made fibres. The details about these fibres are as follows:

a) Natural fibres

Natural fibres had been used to reinforce building materials such as cements, plasters and muds (Coutts, 1990). The classification of the fibres is depicted in Figure 2.1. Natural fibres provide several advantages including: they occur in abundance and are of low cost (Raju et al., 2008); they pose minimum health risks (Mashitah et al., 2011); and have low density, desirable fibre aspect ratio and have relatively high resistance to tension and bending (Buitrago et al., 2015). In the building industry, the interest in natural fibres is because of the economic and technical aspects including the high insulation properties they poses as compared with other materials (Allan et al., 2004). Furthermore, Natural fibre have good specific mechanical properties of strength and toughness and lower density than synthetic fibres like glass and carbon or aramid (Quijano-solis, 2015).

This study focusses on the use of plant leaf fibres in the name of pineapple leaf fibres. On average, about 22 units of pineapple leaves weigh one (1) kg, and the reported fibre yield is about 2.7 to 3.5% of fibres (Alexandre, 2005; Leão et al., 2010). The extraction of 100 kg of leaves yielded 3.5 to 4.0 kg of the pineapple leaf fibres by the process of shredding (Doraiswamy and Chellamani, 1993). The study of mechanical and physical properties of jute and pineapple composites revealed that their properties are highly depend on geographic origin of fibres, climatic growth conditions and processing techniques (Repon et al., 2017). A study of pineapple leaf fibres for 12 different varieties of pineapple plant characterized them on their morphology, structure, chemical composition and mechanical properties (Sena et al., 2015). Figure 2.1 shows the classification of natural fibres.

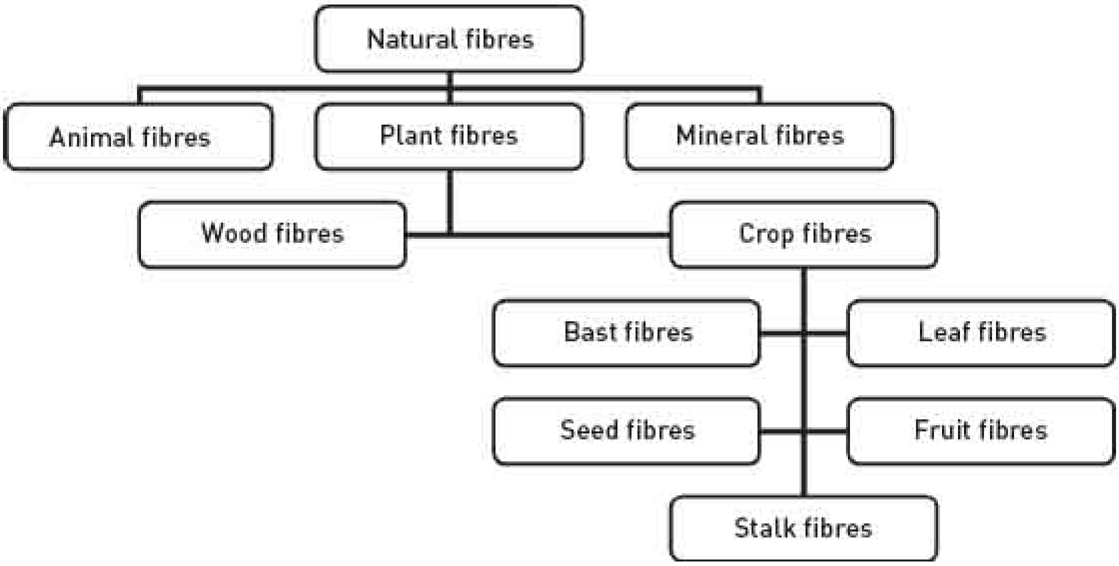


Figure 2.1: Classification of natural fibres.

The use of pineapple leaf fibres not only replaces or substitutes the expensive synthetics fibres, but also improves the mechanical performances of the composite (Wahyuningsih et al., 2016). The development of bio composites by reinforcing natural fibres has attracted attention of scientists and researchers due to environmental benefits and improved mechanical performance(Namvar et al., 2014). Among different types of natural fibres, pineapple leaf fibres show outstanding properties including richness in cellulose content, cost-effectiveness, eco-friendliness and having good fibre strength (Nasir et al., 2017). Pineapple leaf fibre is one of the natural fibres like sisal, banana, jute, oil palm, kenaf and coir that has been used as reinforcement in thermoplastic composite and civil engineering structures. (Munirah et al., 2007). Figure 2.2 shows pineapple leaf fibre.

Figure 2.2: Pineapple leaf fibres.
Source: Andrade et al. (2015)

Natural fibres are one such proficient material which replaces the synthetic materials and its related products for the less weight and energy conservation applications(Sanjay et Al. 2016). The advantages and disadvantages of natural fibres are listed in Table 2.1.

Table 2.1: Advantages and disadvantages of natural fibres

Advantage	Disadvantage
Low specific weight results in higher specific strength and stiffness than glass	Lower strength, especially impact strength
Renewable resources, production requires little energy, low CO_2 emission	Variable quality, influenced by weather
Friendly processing , no wear of tools and no skin irritation	Power water resistance, which causes swelling of the fibres
Production with low investment at low cost	Restricted maximum processing temperature
Good electrical resistance	Low durability
Good thermal and acoustic insulation resistance	Poor fire resistance

Source: Tajuddin et al. (2016)

b) Synthetic fibres

Synthetic fibres are artificially made and are the most widely used in the laboratory testing of soil reinforcement. Figure 2.3 shows the classification of synthetic fibres.

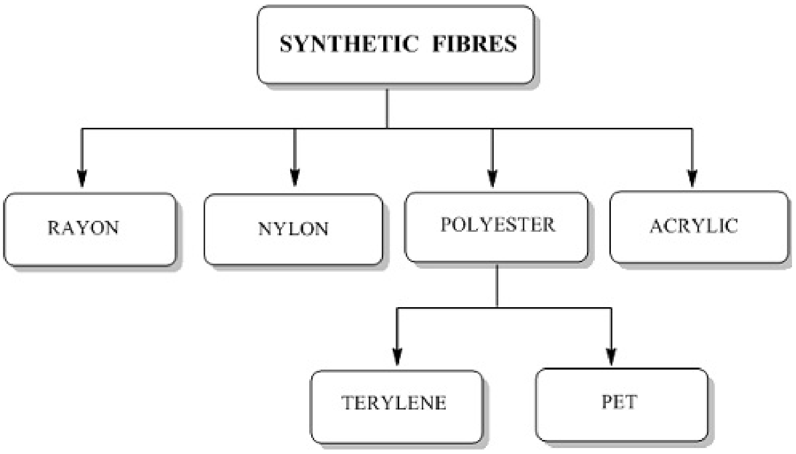


Figure 2.3: Classification of synthetic fibres.
In the figure: PET is polyethylene terephthalate.

Synthetic fibres are more durable than most natural fibres and will readily pick-up different dyes. In addition, many synthetic fibres offer consumer-friendly functions such as stretching, waterproofing and stain resistance. Sunlight, moisture, and oils from human skin cause all fibres to break down and wear away. Natural fibres tend to be much more sensitive than synthetic blends. This is mainly because natural products are biodegradable. Most of synthetic fibres have the following disadvantages (Amezugbe, 2013): synthetic fibres do not burn more readily than natural; they are prone to heat damage; they melt relatively easily; they are prone to damage by hot washing; more electrostatic charge is generated by rubbing them than with natural fibres; they are not skin friendly, so it is uncomfortable for long wearing; they are allergenic to some people; and they are non-biodegradable in comparison to natural fibres.

2.1.2 Fibres attributes affecting the strength of soil blocks

There are two important factors that contribute to the strength development of fibre enhanced blocks. These are: fibre content (i.e., the fraction of fibre in the soil) and the fibre aspect ratio (i.e., the ratio of length to diameter of the fibre) (Building, Street, Kingdom, & Education, n.d.).

2.1.3 Durability of natural fibres

Durability of a material, in general is defined as the service life of a material under given environmental conditions; In fact, in order to enhance the durability of vegetable fibres when used in concrete mix, several methods of treatment were investigated (Toledo et al., 2003). One of these treatment methods is by chemical solutions, which improves the adhesion between the fibre surface and the cement matrix, hence, reducing the fibre moisture absorption, increasing the surface roughness of the fibres, removing waxes and oils from the surface of the fibre, and mainly increasing the durability of the fibres in the concrete composite (Machaka et al., 2014; Azman et al., 2010).

Furthermore, Regina et al. (2015) noted that vegetable fibres have poor moisture resistance and they degrade easily. To solve the degradation problem and improve on its engineering properties vegetable fibres are degummed chemically (Wang et al., 2008). This involves treating the fibres with alkaline solution (viz., sodium hydroxide, NaOH) in order to increase its durability (Mohan and Manjesh, 2017). In many studies the use of NaOH is found to be the most appropriate (Jose et al., 2016). A study conducted by (Devi et al., 1996) has shown that composites containing NaOH treated fibres exhibit the lowest water absorption sorption. The reaction that takes place as a result of alkali treatment with the fibre is as follows: Fibre – OH + NaOH → Fibre – O– Na^+ + H_2O (Sepe et al., 2017).

On other hand, it has been established that the time duration of treatment and the quantity of chemical solution used play important role in the performance of the fibre (Asim et al., 2018). Therefore, it is very important to be careful with the use of NaOH while treating natural fibres since the chemical is required to increase both durability and performance of the fibres.

2.1.4 Fibres aspect ratio

Though the length of the fibres is crucial for the reinforcing effect, the more important parameter is the fibre aspect ratio (Peltola et al., 2011). Many other studies have commented on the significant of fibre aspect ratio. For instance, Amuthakkannan et al. (2013) stated that the most important factors in the short fibres reinforcement are fibre dispersion and fibre aspect ratio. The homogeneous fibre dispersion is the most important factor to enhance the mechanical properties. Similarly, Katzer (2006) reported that the most important of them is the aspect ratio of the fibres, which influences the workability and spacing of fibres in fresh concrete mix. Because of workability, the concrete mix aspect ratio of steel fibre should not be higher than 150. Finally, Dalvi et al. (2016) stated that sisal fibre of aspect ratio 50, 75,100 were used to reinforce concrete and it was found out that the specimen reinforce with fibre of Aspect Ratio 50 gave the highest the compressive strength.

2.2 Conceptual Framework

This part of the study reviews the main concepts of stabilisation of earthen construction, the conceptual framework used in this study is presented in Figure 2.4.

2.3 Empirical Review

In recent years, a lot of scientists and engineers have started utilizing plant fibres as effectively and economically as possible to produce good quality fibre to reinforce composites material for structural, building, and other needs (Kamel et al., 2011). In Malaysia, several initiatives have been done in order to extract fibre from pineapple leaves and convert into commercial products (Yusof et al., 2015). The advantages of natural fibres are beneficial and not likely to be ignored by the building, appliance, and other applications (Kowalski, 2010). On the other hand, cellulose is a polymer provide the fibre with a big Young Modulus of about 136 GPa compare to 75 GPa of glass fibre (Elouaer, 2011).

2.3.1 Engineering properties of natural fibre

In general, the most important properties of the natural fibres to study are chemical composition and mechanical properties. Although natural fibres exhibit admirable physical and mechanical properties, it varies with the plant source, species, geography, and so forth.

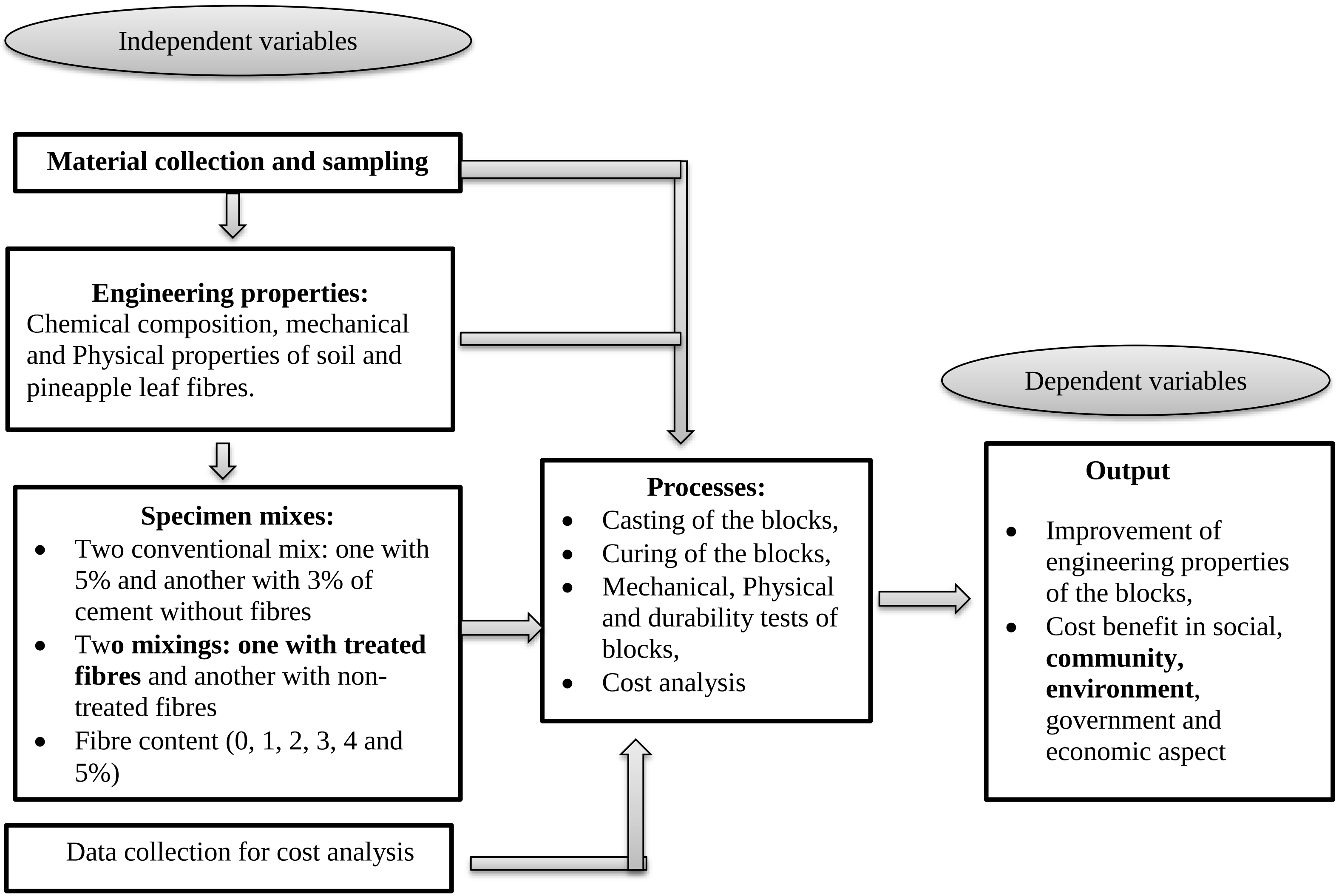


Figure 2.4: Conceptual framework

a) Chemical composition of natural fibres

Among many natural fibres, pineapple leaf fibre has low lignin when compared with banana stem, oil palm and coconut and this low lignin content enables pineapple leaf fibres to have a high strength and this makes it difficult to break (Daud et al., 2014). An example of chemical composition analysis of some fibres is given in Table 2.2.

Table 2.2: Chemical composition of important plant fibres

Plant	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Pineapple	81	-	13
Sisal	73	13	11
Banana	63	19	5

Buitrago et al. (2015)

Pineapple leaf fibre can be deemed as fortunate to be missing the hemicellulose since it increases the tensile strength of the fibre whilst maintaining a longer lifespan, because higher content of hemicelluloses causes higher moisture absorption and biodegradation (Adam, 2016).

b) Physical and mechanical properties of natural fibres

The physical-mechanical properties of any natural fibres depend on fibre matrix adhesion, volume fraction of fibre, aspect ratio, orientation, and stress transfer efficiency at interface. The main properties of pineapple leaf fibres are tensile strength, density, diameter, moisture content and Young’s modulus (Leão et al., 2015). The properties of pineapple leaf fibres are similar to those of many other leaf fibres such as ramie, flax and jute, (Yu, 2001). Table 2.3 shows the physical and mechanical properties of some important natural fibres; The superior mechanical properties of pineapple fibre are associated with its high cellulose content (Devi et al., 1996).

Table 2.3: Physical and mechanical properties of some important natural fibres

Fibre	Density (g/cm^3)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)
Flax	1.50–1.53	450–1100	27.6	2.7-3.2
Sisal	1.45	468–640	9.4-22	3-7
PALF	1.44	413–1627	34.5-82.5	1.6
Ramie	1.50	400–938	61.4-128	1.2-3.8
Jute	1.30–1.45	393–773	13-26.5	7-8
Cotton	1.50–1.60	287–800	5.5-12.6	7-8
Coir	1.15	131–175	4-6	15-40

Source: Danso et al. (2014). In the table: PALF is pineapple fibre

According to the results shown in Table 2.3, the highest tensile strength of fibres was obtained with pineapple leaf fibre. All the others fibres listed, flax (Hejazi et al., 2012), sisal (Jiesheng et al., 2014), ramie (Banowati et al., 2016), jute (Kumar et al., 2015), cotton (Sharma et al., 2017) and coir (Maurya et al., 2015) have been used to reinforce soil block and other composite materials. However, there is then the research gap which needs to be fulfilled by using pineapple leaf fibres to reinforce soil block to see how its high mechanical strength can affect soil blocks.

2.3.2 Engineering properties of lateritic soils

a) Chemical properties of lateritic soils

Mineral content is the principal factor controlling the chemical properties of soils (Kamtchueng et al., 2015). According to (Mustapha, 2012), chemical properties of lateritic weathering profile vary essentially with depth, location, climate and site geology. The study found that variation of chemical properties of oxides compositions (SiO_2, Al_2O_3, Fe_2O_3, K_2O, $SiO_2/Al_2O_3+Fe_2O_3$) content in laterite soil vary at each level. The higher percentage composition of Fe_2O_3 is found at 1.0 m depth and this is an indication of matured laterite, this kind of laterite is the most appropriate for soil blocks (Mustapha, 2012). Also it is known that, the presence of iron oxides allows stabilization to occur efficiently with little cement, as a result of Pozzolanic reactions or hardening effects (Rigassi, 1995). Olawuyi et al., (2016) further stated that the good soil for block should have alumina (Al_2O_3) or clay of 20-30 percent by weight; silica (SiO_2) or sand of 35-50 percent by weight, and silt of 20-25 percent by weight.

b) Physical properties of laterite soils

The physical properties of laterite soil play a big role in the engineering properties of it blocks, the physical properties required for soil before it application are essentially: Liquid limit (%), Plastic limit (%),Plasticity index (%), Clay (%) , Silt (%), Fine sand (%), and Coarse sand (%), and moisture content according to BS 1377: 1990, (Ismail et al., 2011). In general, according to (Abdullah et al., 2017) it is showed from experimental results that laterite soil is more suitable than clay for Compress Stabilize Earth Block (CSEB) production.

Soil is a very non-homogenous material and therefore stabilization is not the only factor that affects block performance. Compaction energy, soil characteristics such as particle size distribution and Atterberg limits, moisture content, drying regimen and other factors also have a large impact (Danso et al., 2014).

2.3.3 Performance of alternative materials for construction of buildings

a) Techniques of stabilisation

The stabilisation of soil can be done through several ways. Rigassi (1985), identified six categories Table2.4 of stabilising soil for construction purposes.

Table 2.4: Stabilisation techniques

Technique	Explanation
Increasing density	This is done by creating a dense environment, blocks pores and capillary channels by application of force (compression).
Reinforcing	This technique involves the use of fibrous materials such as fibres form organic origin (agricultural waste), animal origin (wool or hair) and synthetic origin (polythene) in increasing the properties of soil.
Cementation	This technique uses cementious materials to bind and improve the engineering properties of the particles of soil. Some of the materials used are lime, Portland cement, glues and resins
Bonding	This technique uses chemicals such as acids, flocculants, lime, polymers, etc. to stabilise the soil.
Water-proofing	This technique add materials that expand and seal off access to pores such as bitumen and bentonite to soil to stabilise it.
Water-dispersal	This is done by modifying the water in the soil to improve the properties of the soil. It uses chemicals such as resins, calcium chloride and acids to eliminate the absorption of water.

Source: Danso (2017)

b) Performance of soil blocks reinforced with natural fibres

Prabakar and Siridihar used Sisal fibre at 0.25, 0.5, 0.75 and 1% by weight of raw soil with four different lengths of 10, 15, 20 and 25mm and at 0.75% they concluded that the great result is reached at the length of 20mm,(Mahdi et al., 2012). Waste tea, oil palm empty fruit bunches, lechuguilla, pineapple leaves, cassava peel and hibiscus cannabinus have been investigated as stabilisers to enhance the properties of soil blocks (Bouhicha, 2005; Aouissi, 2005; Demir, 2006; Achenza, 2006; Fenu and Kolop 2010; Haziman, 2010; Juárez, 2010); Guevara, 2010; Chan, 2011; Villamizar, 2012; Araque, 2012; Millogo, 2014; Morel, 2014). Fibrous material addition as a reinforcing element of stabilized earthen block (SEB) is one of the promising outcomes (Sreekumar and Nair, 2013).

During the last decades, the use of fibres as admixtures as complement has greatly grown due to economic and environmental reasons, (Sreekumar et al., 2013). The use of PALF in the laterite soil block will surely reduce the crack and will give ductile to the block due to its natural properties. The following figure shows an example of reinforced composite compare to one non-reinforced. Figure 2.5 shows the failure mode of reinforced and unreinforced soil blocks.

Unreinforced Reinforced

Figure 2.5: Failure of reinforced and unreinforced soil blocks under tension.

Properties of composite reinforced with fibre shows more ductility and small losses of peak strength in comparison to unreinforced material. According to Danso et al., 2014, usage of fibre together with cement material is useful as fibre inclusion helps composite to avoid the brittle behaviour under the use of cement which cemented together the different particle. Earlier studies on the inclusion of coconut, and sisal fibres in soil blocks with a fibre content of 4% of cement, showed a reduction in the occurrence of visible cracks and gave highly ductile blocks.

The fibre increase the strength of the composite. This happens because they provide a highly effective intervention without changing the geometry of the parts,(Luiz et al., 2014). Fibres are very effective in improving the fracture resistance of the matrix since a reinforcement having a long dimension discourages the growth of incipient cracks normal to the reinforcement that might otherwise lead to failure (Avtar et al., 2011). The analysis of sawdust influence in Compress Ground Block (CGB) shown change in the material behaviour, from fragile behaviour to semi-ductile behaviour, also the diagram stress-strain shown a change of the mechanical behaviour of the composites (Ouattara et al., 2016). reinforced soil with decompose palm tree fibre and they reported that at a constant palm fibre length (30mm), with increase in fibre inclusion (from 0 to 1%), and the strengths were increased, (Hejazi et al., 2012). In the similar way, OPEFB fibres have been used as reinforcement for laterite blocks and there is improvement in the soil block at 3% content afterward the soil block started decreasing (Ismail and Yaacob, 2011).

c) Different composites reinforced with pineapple leaf fibres

In an effort to assess the mechanical properties of pineapple leaf fibres, Kowalski (2010), used different percentage of pineapple leaf fibres to reinforce concrete till an optimum percentage value was obtained beyond which the compressive strength decreased. The study established that a control mix compressive strength was obtained as 22.81 MPa for 7 days curing and 34.29 MPa for 28 days of curing. The peak 7th day compressive strength of 27.31 MPa was obtained for concrete mix containing 1% of F/C ratio (%) and it was found to be 20% more than the control mix. On the other hand, a peak 28th day compressive strength of 40.53 MPa was obtained for concrete mix containing 1% of F/C ratio (%) and it was found to be 18% more than the control mix.

Arib et al. (2006) investigated the mechanical properties of pineapple leaf fibre polypropylene composites as a function of volume fraction. Other similar studies by Devi, et al., (1996) established that pineapple leaf fibres polyester composites possess superior mechanical properties compared to other cellulose-based natural fibre composites. Pavithran et al. (1987) carried out a comparative study on the impact of unidirectional aligned polyester composites reinforced with sisal, pineapple, banana and coir fibres and found that sisal fibre composites had the highest toughness followed by pineapple leaf fibres composites. Toughness for fibre reinforced concrete was about 10 to 40 times that of plain concrete (Wafa, 1990).

Arib et al. (2006) studied the tensile modulus and tensile strength of polymer composite reinforced with pineapple leaf fibres. They found that tensile strength of the composites start decreasing with the addition of 16.2% volume fraction. This is because at high volume fraction the fibres act as flaws and are not perfectly aligned with the matrix. In addition, it has higher void content and low interfacial shear strength. Similarly, the mechanical properties of pineapple leaf fibres reinforced polymer composites for application as a prosthetic socket was carried out by Odusote (2016) and the results were found to be satisfactory with chemical surface treatment.

The determination of engineering properties of pineapple leaf fibres-reinforced concrete was made by de Aro et al. (2012). The results were compared with those of a conventional plain concrete beam when subjected to flexural and tensile tests. The strength between the plain and the fibre-reinforced concrete beams increased with fibre reinforced concrete. In addition, the tensile modulus and elongation at break of the poly (lactic acid) composite containing 40% pineapple leaf fibres were about 48%, and 111%, respectively, compared with that of poly lactic acid non-reinforced one (Kaewpirom et al., 2014).

Elsewhere, a study on stress relaxation behaviour of pineapple leaf fibres reinforced polyethylene composites established that the stress relaxation decreased with increase in fibre content due to better reinforcing effect (Arib et al., 2006). From the most recent studies, pineapple leaf fibres has been chosen as a reinforcement instead of other fibre (Yusof et al., 2016). Linto-Mathew et al. (2017) added pineapple leaf fibres to the concrete and they found out with good results.

d) Pineapple leaf fibre in soil stabilization

For now pineapple leaf fibre is still new raw material in civil engineering field, it is used for long time in many other field. Among a few example of it use in soil reinforcement, pineapple leaf fibres has been used to improve the engineering properties of clay soil before construction by soil stabilization techniques (against Excessive settlement and limited strength of clays). The test results indicate that the CBR values of soil increases with increase in fibre content.(George et al., 2016).

On the other hand, as pineapple leaf fibres which has been used for long time in polymer composite reinforcement, textile, and many other field, also OPEFB fibre-reinforced polymer composites and its incorporation into polymeric materials leads to several interesting consequences on the water absorption characteristics and the mechanical properties (Azman et al., 2010). The fibres increase the modulus of the matrix material. They also reduce the permeability of concrete and thus reduce bleeding of water (Wikipedia, 2017). Figure 2.6 shows the fibre inclusion within the composite.

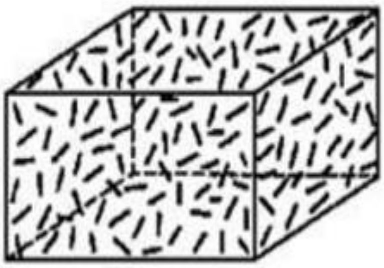


Figure 2.6: A schematic showing the inclusion fibres in a block.

According to (Mohammed et al., 2015), it was found that, there are number of aspects that affect the performance of reinforced composite, of which to name a few are: Orientation of fibre, Strength of fibres, Physical properties of fibres, and Interfacial adhesion property of fibres and many more.

e) Strength of soil blocks according to codes

New Mexico Code indicates a compressive strength of the material (the minimum needed for the achievement of the soil walls), of 2.07 N/mm^2. The Zimbabwe Code requires, for the 400 mm wall thickness, a minimum compressive strength of 1.5 N/mm^2, to the one level houses and a minimum of 2.0 N/mm^2 , in the case of two-storey houses. The Australian Standard indicates a minimum compressive strength of 1.15 N/mm^2 and ASTM International E2392/E2392M-10e1 (2010) indicates a value of 2,068 N/mm^2. The ACI Material, Journal Committee indicates compressive strength values depending on the soil composition, as follows: 2.76 to 6.89 N/mm^2 in the case of sandy soil, and from 1.72 to 4.14 N/mm^2 for clay soil (Calatana et al., 2016) . Minimum strength of at least 3.5N/mm^2 for load bearing walls as suggested in the

Tanzania Standard, TZS 283:1986. Considering the functional and quality requirements of the blocks it was found that with 7% cement content as a stabilizer the strength achieved at 28 days was 2.93 N/mm^2 well above the minimum of 2.5/mm^2 recommended for low cost housing (Low Cost Housing Technologies in Kenya, 1996).

2.3.4 Cost-benefits of using alternative materials for construction of buildings

a) Definition

Cost-benefit analysis is a systematic approach to estimate the short and long term consequences: measuring all costs and all possible profits and benefits from an investment project proposal, taking into account both quantitative and qualitative factors.

b) Why undertake a cost-benefit analysis

In general, the main reason for undertaking a cost-benefit analysis is to determine whether a project, will make the wider community better or worse off. In other words, whether the net impact of the project is positive or negative(Management & Material, 1983). The key steps of course benefit analysis are listed in Plate 2.1.

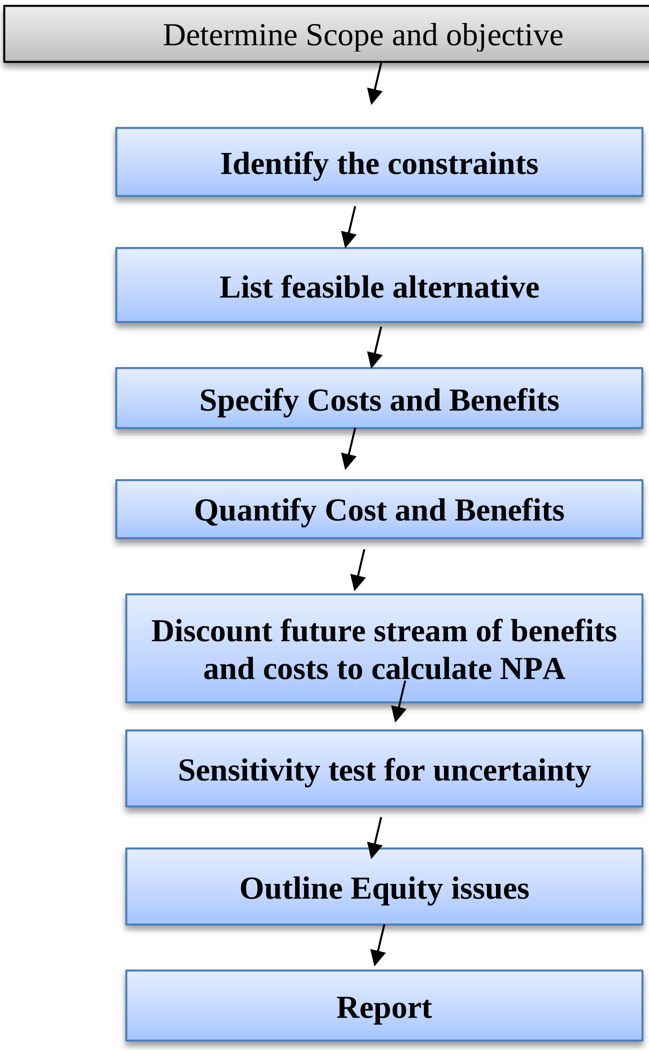


Plate 2.1: Key steps in the cost-benefit analysis process
Management & Material (1983)

To identify the economic benefit of making any given investments, and select and rank the project from numerous investment options, cost benefit analysis is the best way.

c) Project benefit of using an alternative building material

The benefits of using an alternative building material are divided into five aspects; namely social and community, environmental, government, economic and others. These different aspects are described as follows. First are the social and community aspects which include job creation opportunities in the local community in construction area. Further, cement stabilized blocks reinforced with fibres do not need skilled employees to make. Second, environmental aspects which include the building made with soil block is reduces warm (heat) gain. Since cement stabilized soil blocks do not need a lot of cement that will reduce the emissions from cement plants which cause greatest concern and which need to be dealt with are dust, carbon dioxide, nitrogen oxides and sulphur dioxide (Stajanca et al., 2012). Also, using stabilized soil blocks instead of burned blocks is estimated to save the felling of 14 trees when building a 4 x 4 m house (UN-HABITAT, 2013).

Further, as for the government aspects, the job opportunities that will be offered by the green building will increase the number of employees in the state and this will assist the government to earn more tax revenue from the employees and corporate. Lastly, as for the economic aspects, about economic aspect, using cement earth stabilized block will help poor people to build their house with less money. On other hand, Comparative cost estimates of soil stabilized block (SSB) and burnt block (BB) for construction of a two bedroom house with kitchen and toilet facilities on a 225 square meters plot, shown that with BB there is increase of SGD 6.240 over the one of SSB, (UN-HABITAT, 2013). According to Wilson et al. (2016) the use of laterite-cement blocks can greatly reduce the cost of construction by up to 30% savings when compared to the use of sand concrete blocks.

In most developing countries, the dream of owning a house particularly for low income and middle-income families is becoming a difficult reality due to the rising costs of building materials (Tam, 2011). Because of this, it has become a necessity to adopt cost effective and environment-friendly technologies for the construction of houses and buildings by finding an alternative material for cheap house. So far, there have not yet been cost benefit analysis on cement earth block reinforced with natural fibre that is a research gap which needs to be done in the present study.

2.4 Research Gaps

The need to undertake this research is the gaps identified during the review of the relevant literature on stabilisation or enhancement of soil/earth blocks/blocks capacities. The majority of these studies were conducted in developed countries: Montgomery (2002) from United Kingdom; Obony (2011) from United States of America; Akbulut (2007) from Turkey, Heathcote (2002) from Australia; Achenza et al. (2006) from Italy; Burroughs (2006) from Australia; Delgado and Guerrero (2006) from Spain; Chan (2011) from Malaysia; Gidigasu (1976) from Netherland; Graham and Burt (2001) from Mexico; and Adam and Agib (2001) from France.

Developing countries like African countries are the most likely to benefit from this technique due to high housing issues. However, not much research work is seen in these areas. There is the need to fill this gap by extending the study on the phenomenon to the developing economies to better assess the strength and durability properties of soil blocks and to advance the production of low-cost houses.

Secondly, most of the studies in the phenomenon used cement, lime and other binders as the stabiliser for the blocks. Other studies also combined cement with fibres (Binici et al., 2005; Arumala et al., 2007; Juárez et al., 2010; Vilane, 2010; Medjo et al., 2012; Obonyo et al., 2012; Chan, 2011). The treated PALF in sodium hydroxide solution have always shown the highest strength value in the reinforced polymer composite (Asim et al., 2018; Hashim et al., 2018; Siregar et al., 2010). Hence, it is important to fill the gap by using treated PALF to reinforce soil block to see if it increases the strength more than those which are not treated. Pineapple leaves fibres have shown an outstanding potential in many composite such as polymer, polystyrene.

Thirdly, so far there are many studies about the use of natural fibre from agricultural waste to enhance the strength of soil blocks, those fibres are oil palm fibres (Ismail and Yaacob, 2011), coir fibre (Aguwa, 2013), fibrous coir wastes (Sreekumar and Nair, 2013), sugarcane bagasse fibre (Danso et al., 2015), wheat straw (Farooqi et al., 2016), Kenaf fibres (Millogo et al., 2015), and seaweed (Dove, 2014) as enhancement for soil blocks/blocks. Actually, the results of these studies indicated an improvement of engineering properties of the blocks/blocks. There is a need to extend the study to other agricultural waste such as pineapple leaf fibre which is the most available plant in African around (44 countries) as an enhancement of the mechanical as well as durability properties of soil blocks to be used as walling materials for producing low cost houses.

Fourthly, few studies included cost benefit analysis in their research work. The cost-benefit analysis is very important because it will show if the new techniques are really beneficial. Hence, in this study cost-benefit analysis is going to be done to find out either it is beneficial or not.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Introduction

This chapter deals with the methodology that was used in the study. The study established the feasibility of using pineapple leaf fibre for reinforcing laterite soil blocks stabilized with cement for construction of low-cost buildings. The main engineering properties that were studied included compressive strength, flexural strength, split tensile strength, density, abrasion, erosion and water absorption. Four (4) specimens were used in the study, the first two (2) specimen were stabilized soil blocks with 3% of cement and respectively reinforced with treated and non-treated pineapple leaf fibres. The other two (2) specimen were soil blocks stabilized with 5% of cement and respectively reinforced with treated and non-treated pineapple leaf fibres. Analyses of the materials and actual laboratory tests were all undertaken at different laboratories. Finally, cost-benefit evaluation was conducted for using laterite soil blocks reinforced with pineapple leaf fibres for construction of buildings.

3.2 Assessing the Engineering Properties of Laterite Soils and Pineapple Leaf Fibres

3.2.1 Material acquisition

The study was conducted at Jomo Kenyatta University of Agriculture and Technology (JKUAT) from February to July 2018. JKUAT is located in Juja Township, 10 km West of Thika town and 45 km East of Nairobi, Kenya. The latitude, longitude and altitude of the location are 1.18^{o}S, 37^{o}E and 1460 m above sea level, respectively. The following materials were used:

a) Laterite soil and sand

The soil and sand were procured from Juja and Nyeri, respectively. The soil was kept under polyetilene cover to ensure that it was neither too dry (by sun dry) nor too wet (by rain). The soil was obtained from excavation on construction site.

Figure 3.1: Laterite soil.

b) Cement

Pozzolanic cement CEM IV/B 32.5R used in the study was formulated in accordance to the KS EAS 18-1:2001, which is adopted from the EN 197-1 European Standards. It was procured from the nearest hardware in Juja.

c) Pineapple leaf fibres

Pineapple leave fibres used for this study were obtained from Hand Conifer Company Ltd, Mumbai, India as the extraction machine was not available in Kenya. The fibres were extracted mechanically using the extraction machine. Actually, we can still make the extraction locally manually in Kenya but it will take more time since there is no extraction machine of pineapple leave fibre around. The fibre-extraction methods have a major impact on yield and quality of fibre (Joffe et al., 2003; Jose et al., 2016) and for this reason, specific designed machines were required for its extraction.

d) Water

Potable water conforming to BS 1348-2(1980) was used for mixing the materials (cement, sand and the laterite soil) and for curing the block samples. The water was obtained from general supply water system of JKUAT University, which is of acceptable quality for construction.

3.2.2 Data acquisition and analysis

a) Determining the physical properties of the soil

The physical properties for the soil that were examined included moisture content, maximum dry density, Atterberg limits and particle size distribution. The moisture content was determined according to BS 1377: 1990. Dry density, Atterberg limits and particle size distribution were analysed at JKUAT, as per to BS 1377-2: 1990 (BS 1377-2: 1990, 1990).

b) Determining the chemical properties of the soil

As for the chemical composition, the soil was assessed for proportions of silicon oxide (SiO_2), aluminium oxide (Al_2O_3), calcium oxide (CaO), magnesium oxide (MgO), sodium oxide (Na_2O), potassium oxide (K_2O), titanium oxide (TiO), manganese oxide (MnO), ferrous oxide (Fe_2O_3) and loss on ignition (LOI) which represents the mass of moisture and volatile material present in a sample. The volatile materials lost usually consist of 'combined water' and carbon dioxide from carbonates. These properties were analysed according to BS 1377-3:1990 (BS 1377-3:1990, 1990) at the laboratories of the Ministry of Mining and Petroleum, Government of Kenya.

c) Sodium hydroxide treatment of pineapple leaf fibres

In order to assess the chemical properties and tensile strength of the pineapple leaf fibres, it was necessary to treat the fibres in a 4% of sodium hydroxide (NaOH) solution over various durations. The NaOH treatment is one of the best treatment used for natural fibres. It helps to increase the fibre surface roughness by chemically modifying and cleaning the fibre surface (Ahad et al., 2009). The 4% NaOH solution was prepared by dissolving 80 g of NaOH in 2000 cm^3 of distilled water then divided into four (4) portions. Thereafter, four (4) samples of pineapple leaf fibres, each weighing 70 g, were immersed in 4% NaOH solution for 30, 60, 120 and 180 minutes, respectively. The control treatment involved no immersion of the fibres in the NaOH solution, and this represented zero (0) minutes duration of immersion.

d) Evaluating the chemical properties of pineapple leaf fibres

The chemical properties (i.e., proportions of cellulose, hemicellulose and lignin) of the treated four (4) fibre and untreated fibre samples were determined based on the procedure described by Direct method of cellulose, hemicelluloses and lignin of Moubasher et al., 1982. The analysis was conducted at the Food Laboratory, Department of Food Science and Technology, Jomo Kenyatta University of Agriculture and Technology.

The following methodology was used for each for each of the five sample; to use this method, 2 g of fibre was boiled in ethanol (4 times) for 15 minutes, washed thoroughly with distilled water and kept in oven for dry weight at 40°C overnight, then divided into two parts in which one part was considered as A fraction. Second part of residue was treated with 24% KOH for 4hrs at 250C, washed thoroughly with distilled water dried at 800C overnight and the dry weight taken as B fraction. The same samples again treated with 72% H_2SO_4 for 3 hours to hydrolyse the cellulose. H_2SO_4 was removed completely by washing it with distilled water, dried at 800C in oven for overnight and dry weight taken as C fraction (Brindha et al., 2012). The chemical composition were determined as: cellulose = B-C; hemicellulose = A-B; and lignin = C itself.

e) Tensile strength of pineapple leaf fibres

Tensile strengths for all the samples were determined by recording maximum force at yield/break of the fibres using the Hounsfied tensometer machine shown in Figure 3.2. This test was conducted as per the ASTM D 3822-07 standard. Equation (3.1) was used for determining the tensile strength (τ_s) of the fibres. In the equation (3.1), F_{max} (N) is the force at yield/break of the fibres and A (mm) is sectional area of the fibres.

$$\tau_s = \frac{F_{max}}{A} \tag{3.1}$$

The highest tensile strength for the treated fibres was compare with that for the untreated fibres. After this test a Scanning electron microscopy (SEM) analysis was done on the fibres with the highest tensile strength since this property is important in composite reinforcements. The SEM test was conducted at the Botswana Institute for Technology Research and Innovation (BITRI), Botswana, with 2.0 K X magnification.

The aim of the SEM test was to establish the effect of NaOH solution treatment on pineapple leaf fibres at optimum tensile strength.

Figure 3.2: Measuring fibre tensile strength using the Hounsfied tensometer.

f) Lengths and diameters of fibres

The lengths of the fibres were measured with a steel rule, to do this the fibres were straightened along the ruler and the measure of 30mm were cut. The diameter of the fibre was determined using electronic digital calliper MT-111101G of Measuring as shown in Figure 3.3 Range 0 to 150mm with resolution of 0.01mm.

Figure 3.3: Electronic digital calliper.

g) Aspect ratio of the fibres

The fibre is often described by a convenient parameter called “aspect ratio”. Typical aspect ratio ranges from 30 to 150. The aspect ratio (l/d) is calculated by dividing fibre length (l) by its diameter (d).

3.3 Determining the Engineering Properties of Cement Stabilized Pineapple Leaf Fibre Reinforced Blocks

3.3.1 Blocks preparation

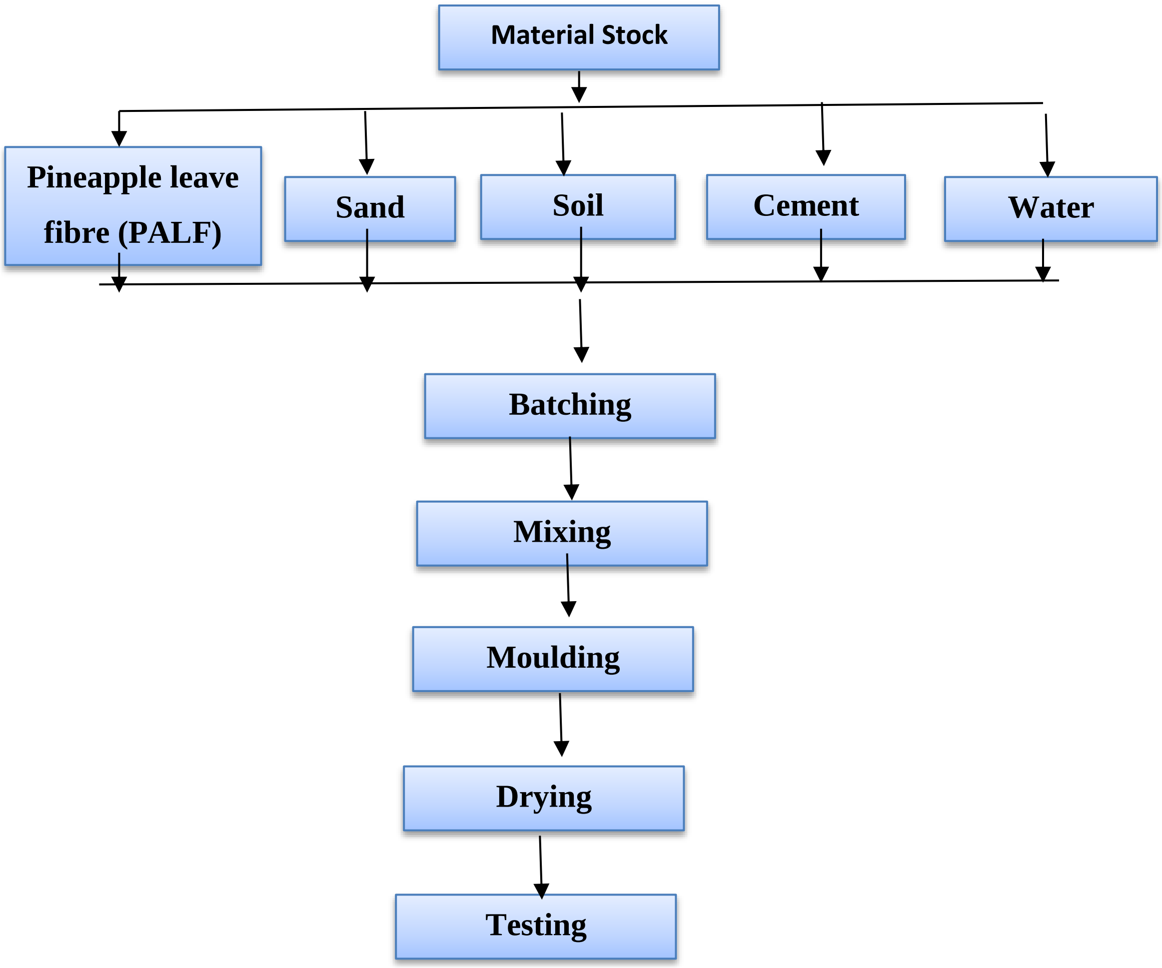


Plate 3.1: Process involved in preparing test samples.

a) Mix design

The mix design for the cement stabilized pineapple leaf fibre reinforced blocks were prepared as follows. First, Portland cement, sand and laterite soil were mixed in proportions of 3, 27 and 70% by mass, respectively, and water was added to form a paste of acceptable range of moisture content (according to the physical test result) forming the first specimen. Another specimen comprising a mixture of 5, 25 and 70% of Portland cement, sand and laterite soil, respectively, was prepared in similar manner. For both specimen, treated and non-treated pineapple leaf fibres were added in proportions of 0 to 5% in steps of 1% by mass of cement.

The length of fibres used in this study was on average 30 mm since it is necessary that the fibres be short and straight enough to enable a quick dispersal without clinging (Ismail et al., 2011). Manual mixing of the material with a shovel (see Figure 3.5) was used to ensure that there is a good dispersion of the fibres in the cement to prevent balling up. Laterite soil and sand were added after mixing cement with the fibres. The mixing process took 10 minutes to ensure that there was an even dispersion of all the materials.

Figure 3.4: Manual mixing of pineapple leaf fibres with cement.

b) Rammed earth mix moisture content drop test

A handful method was used according to The New Zealand Standard 4298 (1998) (4298:1998, 1998) to determine whether or not the moist mixtures that were prepared in Section 3.3.1(a) above were suitable for ramming and subsequently for making blocks. The test requires that a moist soil or soil mixture be placed in palm of the hand, be squeezed once, held up to shoulder height and dropped onto any hard flat surface. Soil that is too dry cannot be formed into a ball. The good soil moisture must be squeezable and be able to take the shape of pressure from the hand of palm. After breaking of the squeezed soil, it should be separate into small particles.

c) Preparation of the blocks

After mixing, three (3) types of blocks, i.e., prism, cube and cylinder were casted. The prism blocks measured 290x140x120mm in length, breadth and height, the cubical ones were 140x140x140mm in length, breadth and height, respectively, while the cylindrical ones were 100mm in diameter by 150mm in height. The prism and cubical blocks were made using a manual stabilized soil block machine (Figure 3.6). The cylindrical ones were made using a cylindrical mould (Figure 3.7) with 100mm internal diameter and 150mm height. The compaction in three (3) layers with standard number of 25 blows was automated. After compaction the blocks were removed from the mould.


Figure 3.5: Making of compressed stabilized prism and cubical blocks.

Figure 3.6: Making compressed stabilized cylindrical blocks.

d) Curing of the blocks

After preparation, the blocks were stacked on timber palettes and marked according to their fibre contents and material composition. The blocks were then wrapped with a plastic film to avoid rapid drying and stored under a sheltered area for 7 days. After the 7 days the blocks supposed to be cured for additional 21 days before further investigations were conducted on them. However, in this study the blocks were covered for the most of time until 28 days because of the weather wet due to rain.

3.3.2 Mechanical properties of the cement stabilized fibre reinforced blocks

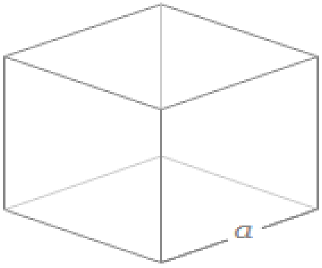
The mechanical properties of the blocks stabilized with 3 and 5% of cement and reinforced with treated and untreated pineapple leaf fibres at 0 to 5% in steps of 1% of fibre were determined using a Servo-plus evolution testing machine shown in Figure 3.8.

Figure 3.7: Servo-plus evolution testing machine.

a) Compressive strength

The compressive strength test was conducted on the blocks after 7, 14, 21 and 28 day of curing in accordance to BS EN 772-1 (2011), The load was applied at a rate of 0.05 N/mm^2/s until the block failed after which the maximum compressive load of the blocks was recorded. The compressive strength (C_s in MPa) was computed using equation (3.2) in which P is the maximum compressive load of the blocks (N) and A (mm^2) is surface area in contact with the platen. Figure 3.9 shown how A (mm^2) is obtained.

$$C_s = \frac{\mathrm{P}}{\mathrm{A}} \tag{3.2}$$



A = a (mm) × a (mm)

Figure 3.8: Cubical shape used to find out the area of the block.

b) Flexural strength

Flexural strength of the blocks was assessed according to ASTM C67-07("ASTM. Standard Test Methods for Sampling and Testing Block and Structural Clay Tile," 2007). Three-points loading system was utilized with one centre point force application on a simply supported block measuring 290x140x120mm. The blocks were centred between the two supports of the hydraulic press under loading so that the span to depth ratio was approximately 2.07. The loading was set at a steady rate of 5 N/s. The flexural strength (f in MPa) of the blocks was determined by equation (3.3) in which F is the maximum force at yield/break (N), L is length of the block (mm), h is height of the block (mm) and b is width of the block (mm).

$$\boldsymbol{f = \frac{3FL}{2bh^2}} \tag{3.3}$$

c) Tensile splitting strength

The tensile splitting test were conducted in accordance with BS EN 12390-6(2009)(British Standards Institution BSI, 2009) after 28 days of curing. The load were applied continuously at a steady rate of 0.05 N/ mm^2/s up to failure of the block as shown in Figure 3.10, and tensile splitting strength recorded. Equation (3.4) was employed to calculate the splitting tensile strength (T in MPa) of cylindrical blocks. In the equation, P is the maximum applied load (N), d and L are diameter and length (in m) of the cylinder, respectively.

$$\mathrm{T} = \frac{2\mathrm{P}}{\pi\,\mathrm{Ld}} \qquad (3.4)$$

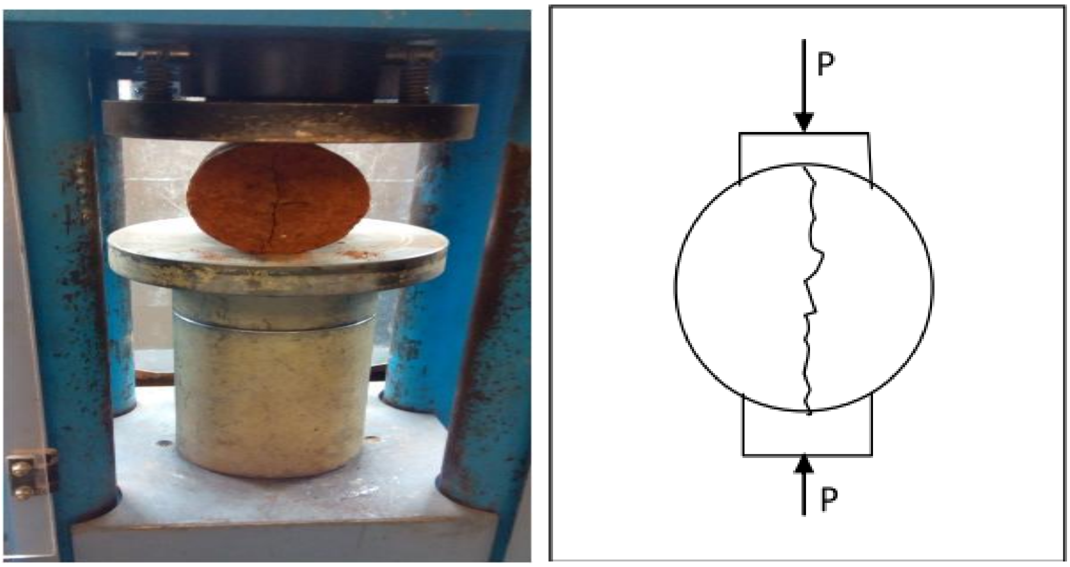


Figure 3.9: Splitting tensile strength set up.

d) Durability test for the blocks

(i) Abrasion test

Each block sample was weighed before the test was conducted. The sample was placed on a flat horizontal table-top secured against sliding as prescribed in AASHTO - T96, 2010. The top side of the sample was given 20 strokes of wire brush as shown in Figure 3.11, after which the sample was reweighed, and the depth of abrasion measured and recorded. The abrasion value (α) was computed by equation (3.5) in which ω_1 (weight before abrasion) and ω_2 (weight after abrasion).

Figure 3.10: Conducting an abrasion test on the blocks.

$$\alpha\ (\%) = 100\left(\frac{\omega_1 - \omega_2}{\omega_1}\right) \tag{3.5}$$

(ii) Earth block drop test

Earth block drop test were made after 28 days of curing of the blocks as shown in Figure 3.12. The blocks were dropped from a height of 900 mm to the point of impact. The test was conducted in accordance with the New Zealand Standard NZS 4298:1998.

Figure 3.11: Conducting an earth block drop test.

3.3.3 Physical properties of the cement stabilised fibre reinforced blocks

a) Determining dry density

The densities of the block samples were determined at 7th, 14th, 21th and 28th days of curing. The test was carried out in accordance to Nigerian Industrial Standard (NIS 87, 2004). Equation (3.6) was utilised to compute the density (ρ) in which m and v are the mass and volume of the block, respectively.

$$\rho = \frac{\mathrm{m}}{V} \qquad (3.6)$$

b) Evaluating the water absorption ability

Water absorption test were conducted as per the EN 771-1:2003 (E) Annex C procedures (STANDARD, 2003). The blocks were placed in oven till they reach a steady state weight (W_1). Thereafter, the blocks were immersed in cold water for 24 hours to absorb water. They were then taken out of water, wiped and weigh again (W_2). Figure 3.13 shows the blocks after the 24 hours in cold water. The percentage water absorption (θ) was determined using equation (3.7).

$$\theta = 100\left(\frac{W_1 - W_2}{W_1}\right) \qquad (3.7)$$

Figure 3.12: Conducting a water absorption test.

3.4 Determining the Cost-Benefit of Using Pineapple Leaf Fibre Reinforced Laterite Blocks

3.4.1 Cost analysis

Cost is the basic and starting point of mass housing provision based on blocks. The procedure used in determining the cost of the blocks was as follows. First the weight of cement, sand, laterite soil (included transportation's fees) and of pineapple leaf fibres were determined. Next, the cost of labour and chemicals material cost were computed. The cost benefit were summarised as shown Table 3.1. The cost of the reinforced blocks were compared to the cost of Interlocking blocks and fired burnt clay block.

Table 3.1: Comparative analysis of the cost of available walling materials per metre square of walls in Kenya

Item	Interlocking blocks	Fired clay blocks	Laterite blocks reinforced with PALF
No of blocks per m^2 of wall			
Unit cost of block			
Cost of blocks or blocks per m^2 of wall			
Cost of bonding mortar per m^2 of wall			
Total cost of a m^2 of wall (N)			
Compressive strength (N/mm^2)			
Savings in cost compared with Fired clay blocks (%)			

In the table: PALF, pineapple leaf fibre

3.4.2 Benefits

The benefits expected to be derived from this study include the following: reduction of the cement content in the soil blocks, increase of the strength of the soil blocks, valorisation of pineapple leaf fibres in engineering field; zero energy consumption by using sun to dry the blocks; random mixer of fibres requires less mechanization and therefore reduction in the number of skilled personnel and low cost of the blocks. Furthermore, it will also have advantage like, economic, social, environmental and governmental.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Physical and Chemical Properties of the Soil

The results of the physical and chemical properties of the soil used in this study are shown in Tables 4.1 and 4.2. The results in Table 4.1 show that the sand and clay proportions are each equal to 20%. This amount of clay is high for making good soil blocks according to (Reddy et al., 2007) . In order to reduce the clay dominance in the blocks some sand was added, because high clay content leads to excessive drying shrinkage, and it lessens durability and compressive strength (Reddy et al., 2007). The average sand particle size was below 5 mm, while the moisture content recorded was 2.36% (dry basis).

Table 4.1: Physical properties of the soil

Properties	**Values**
Proctor test	
Optimum moisture content (%)	31.1
Maximum dry density (kg/m^3)	1351
Atterberg limits:	
Liquid limit (%)	54
Plastic limit (%)	28
Plasticity index	27
Soil classification (USCS)	CH
Particle size distribution:	
Gravel (20 - 2 mm) (%)	2
Sand (2 - 0.06 mm) (%)	20
Silt (0.06 - 0.002 mm) (%)	58
Clay (<0.002 mm) (%)	20
pH	
Value	7.31

CH*: high clay

Table 4.2 shows the chemical composition of the soil. It can be seen that the silica sesquioxides ratio (SiO_2/Al2O_3+Fe_2O_3) of the soil is equal to 1.7. This value is between 1.33 and 2.0 implying that the soil was indeed laterite soil, according to previous research (Pivatto et al., 2013). Laterite soil is the most suitable soil for making blocks because of its stability before the variations of moisture with insignificant change in it properties. All these properties made this soil to be a suitable material for soil blocks.

Table 4.2: Chemical composition of the soil

Chemical composition	**Proportion (%)**
SiO_2	51.31
Al_2O_3	22.26
CaO	1.33
MgO	0.06
Na_2O	2.5
K_2O	1.7
TiO	1.25
MnO	0.34
Fe_2O_3	8.00
LOI	10.00

The particle size distribution of the soil corresponds to result of both dry sieving and hydrometer test, and the results are presented in Figure 4.1. It is observed that 58% of the soil passed through 0.06 mm sieve, indicating that the soil has a fine texture, according to ASTM. The fine texture of the soil confirms its high clay and silt content. Furthermore, it confirms why the soil has high liquid limit and plasticity index values which are not suitable for making soil blocks since this leads to excessive drying shrinkage, and low durability and compressive strength.

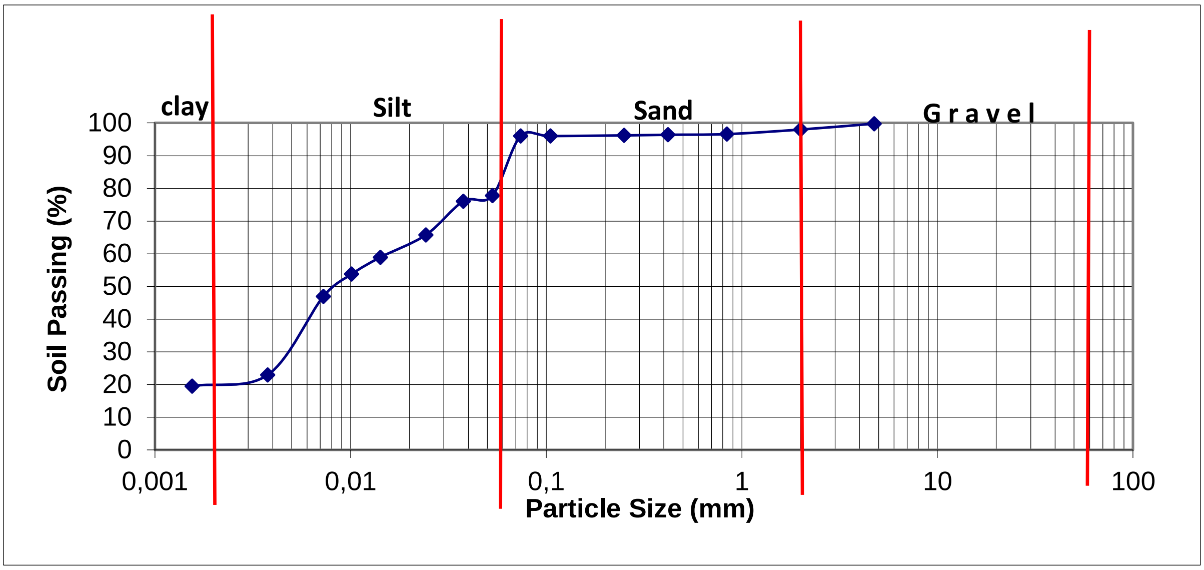


Figure 4.1: Particle size distribution of the soil used for the study.

4.2 Chemical Properties of Pineapple Leaf Fibres

The results for the chemical properties of the pineapple leaf fibres are presented in Table 4.3 and they show that cellulose, hemicellulose and lignin decreased of with increase in duration of treatment of the fibres with sodium hydroxide. This was due to the fact that the sodium hydroxide cleaned impurities from the fibre as shown in Figure 4.2 it can be observed that the treated fibre is clean as comparing to untreated one. The small quantity of lignin present allowed the fibre and the soil matrix to have sufficient adherence, as reported by Asim et al. (2015) and Oushabi et al.(2017). The water absorption was carried out according to ASTM D2842 and the results show that non-treated (N-PALF) and treated (T-PALF) pineapple leaf fibres with sodium hydroxide had 84.4 and 80.5% moisture content, respectively. This indicates that sodium hydroxide had improved hydrophilic properties of the fibre by decreasing the moisture content by 3.96%, implying that pineapple fibre reinforced blocks would absorb less water. The linear density of the fibres were carried out according to ASTM C 693 and the values obtained were 1.43 and 1.36 g/ml for N-PALF and T-PALF, respectively.

The density of the treated fibre decrease because the treatment in sodium hydroxide solution has removed all the impurities from the fibre. And hence it will increase the durability of the fibre.

Figure 4.2: Treated and untreated pineapple leaf fibres.

Table 4.3: Chemical composition of pineapple leave fibres for 4% treatment of sodium hydroxide

Duration of treatment (min)	Chemical composition (%)			
		Cellulose	Hemi-cellulose	Lignin
0	N-PALF	78.68	70.78	10.32
30	T-PALF	75.76	68.44	9.30
60	T-PALF	74.87	67.55	9.26
120	T-PALF	74.61	67.12	9.14
180	T-PALF	74.01	66.81	9.06

In the table: N-PALF is non-treated pineapple leaf fibres; T-PALF is treated pineapple leaf fibres

4.3 Tensile Strength of Pineapple Leaf Fibres

Figure 4.2 shows the relationship between the tensile strength and duration of treatment of the fibres with sodium hydroxide solution. It can be seen that the tensile strength increased with the duration of treatment up to an optimum value about 767 MPa after 107 minutes, thereafter the strength decreased. The tensile strength of the fibres increased after treatment because non-cellulosic materials were removed from the fibres (Oushabi et al., 2017).In addition, according to (Andrade et al., 2015), the diameter of the fibres affects the value of the tensile strength, because the larger the diameter is the lower the tensile strength. On the other hand, the fibre strength started decreasing after one hour of treatment as sodium hydroxide started removing the impurity from the fibres by destroying the fibre cellulose. One hour of the treatment seems to be the best duration for treating pineapple leaf fibres with 4% of sodium hydroxide in order to obtain the highest tensile strength; and this is confirmed by Siregar et al. (2010). It is important to care about the time of treatment of all natural fibres, since this study confirms that the works of other researchers on the treatment of natural fibres, especially with sodium hydroxide.

Regression analysis relating the tensile strength and duration of treatment yielded the relationship presented in equation (4.1). The coefficients of determination (R^2) obtained was high at 0.86 indicating that there is high correlation between tensile strength and duration of treatment. However, the optimum strength obtained above was not used for further analysis in this study as the regression analysis was conducted after completion of data collection. For this study an experimental value of 752 MPa which was obtained after 60 minutes of treatment was used. This value is slightly less by 1.99% of regression value. In the equation, T is tensile strength and t is duration.

$$T = -0.0417t^2 + 8.9048t + 291.49 \qquad (4.1)$$

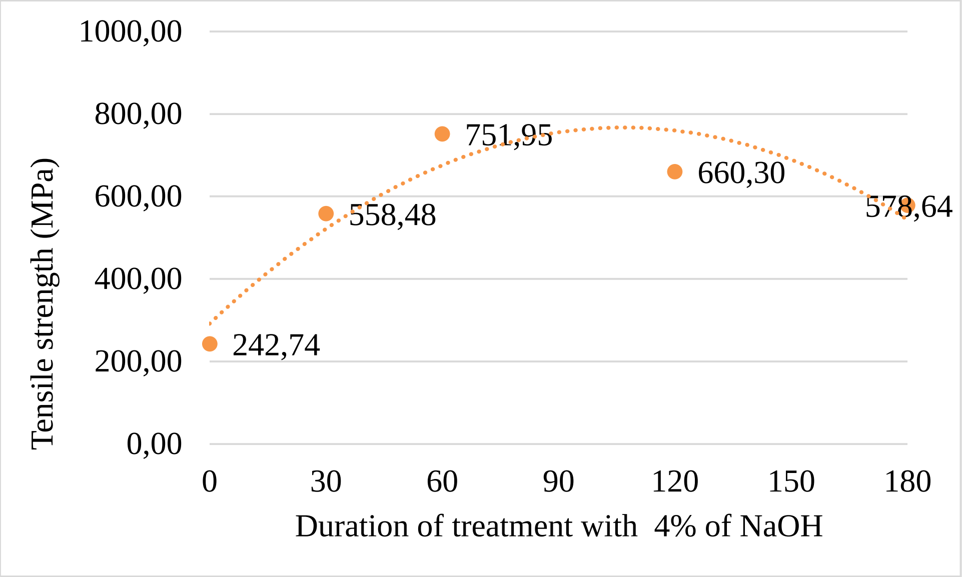


Figure 4.3: Relation between pineapple leave fibre tensile strength and duration of treatment in 4% sodium hydroxide.

The main purpose of the above treatment was to use the fibre with the highest tensile strength for soil reinforcement for making blocks, hence the fibres for one (1) hour duration of treatment were selected. The Scanning Electronic Microscopy (SEM) result for N-PALF and T-PALF for after one (1) hour duration of treatment in sodium hydroxide are shown in Figure 4.3 and 4.4, respectively. By observing the two photos of SEM in the figure it can be seen that T-PALF has a smooth surface compared to N-PALF because the sodium hydroxide treatment has removed the cellulose impurity from the fibres, and this made the fibre to become more flexible and increase its adhesion with the matrix.

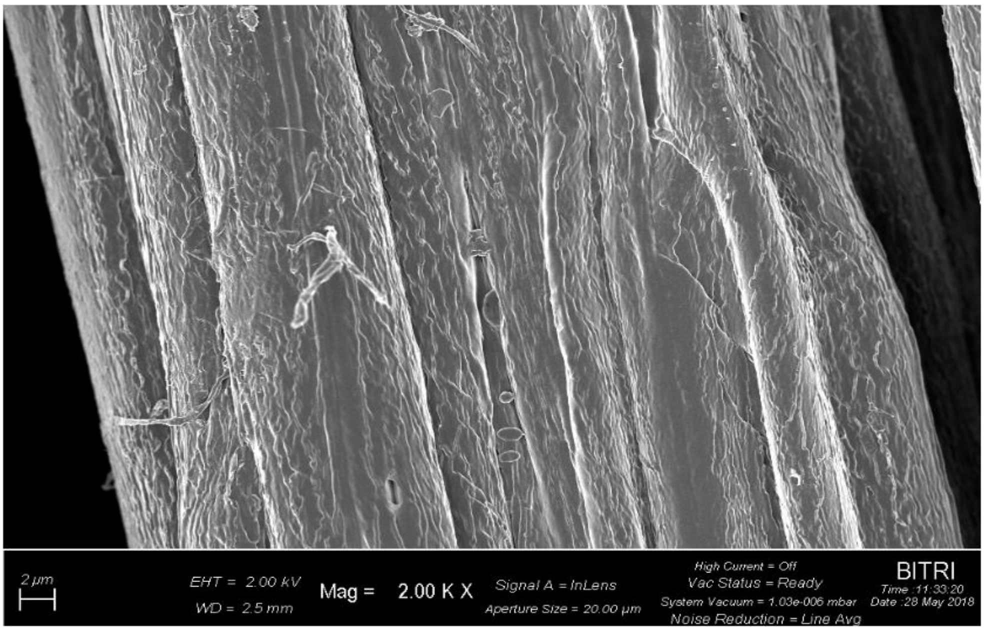


Figure 4.4: SEM test result of untreated pineapple leaf fibres.

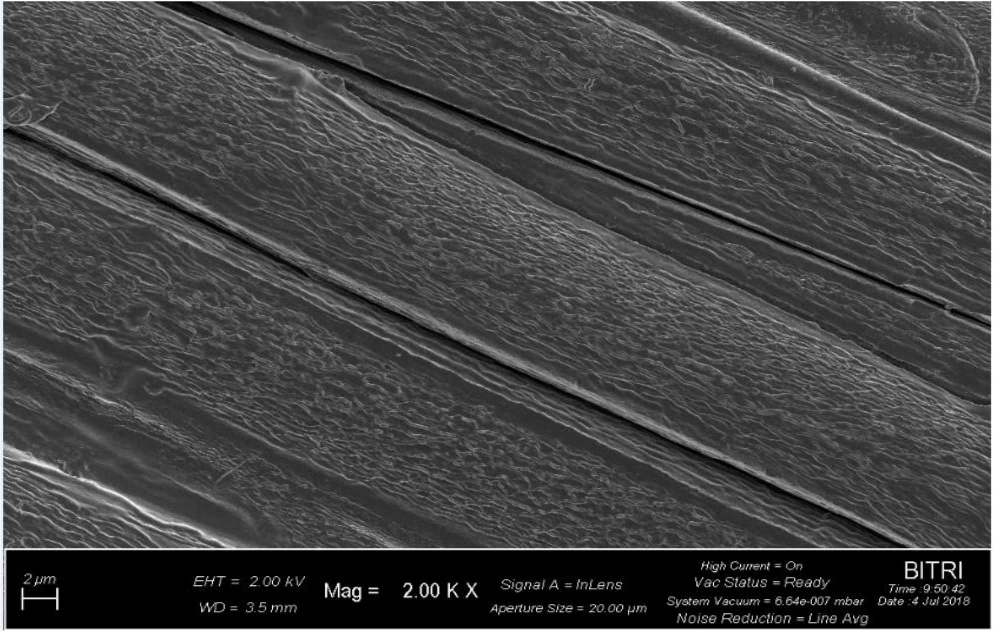


Figure 4.5: SEM result for treated pineapple leaf fibres in sodium hydroxide for one hour.

4.4 Aspect ratio of treated and untreated pineapple leaf fibres

The diameter of N-PALF and T-PALF were 0.162 and 0.123 mm, respectively, indicating that sodium hydroxide reduced the diameter of the fibre. This was the reason why the tensile strength of the treated fibre where higher than untreated ones.

Therefore, the aspect ratio of T-PALF and N-PALF are 243.9 and 185.2. However; it is required that the values lie between 50 and 150 (Gantenbein et al., 2011).

In this study, 30 mm fibre length was employed based on literature of pineapple leaf fibres (Munirah, et al., 2007) in composite reinforcement. This resulted in high aspect ratios beyond recommended values. Therefore, it is important to assess the aspect ratio of any fibre before using it. According to Sudhikumar et al. (2014), a higher aspect ratio decrease the strength of the fibre reinforced composite. It becomes important to do this calculation of aspect ratio of the fibre every time before using any type of fibre in composite reinforcement, as the environment, location, geographic, and so on affect the properties of the fibres (Asim et al., 2015).

4.5 Compressive Strength of Cement Stabilized Blocks Reinforced with Pineapple Leaf Fibres

4.5.1 Compressive strength of blocks stabilized with 3% of cement and reinforced with various proportions of non-treated pineapple leaf fibres

Figure 4.6 presents the relationship between the compressive strength of blocks stabilized with 3% cement and various proportions of N-PALF. It is observed that the compressive strength of the reinforced blocks with N-PALF increased with increase of fibre content up to 3%, thereafter it decreased. According to the ACI Material, Journal Committee all the compressive strengths of the blocks reinforced with 0 to 5% of fibre content at 21 and 28 days of curing met the minimum threshold of 1.72 MPa.

However, the highest value of 3.19 MPa corresponded to the 3% fibre content value at 28 days of curing, hence the focus was on this fibre content value which is also above the minimum threshold of 2.068 MPa recommended by ASTM International E2392/E2392M-10e1 (2010). According to Tanzania Standard 283:1986 (TZS 283:1986) the minimum of strength of 3.5 MPa was recommended for load bearing walls; hence these blocks cannot be used for bearing wall.

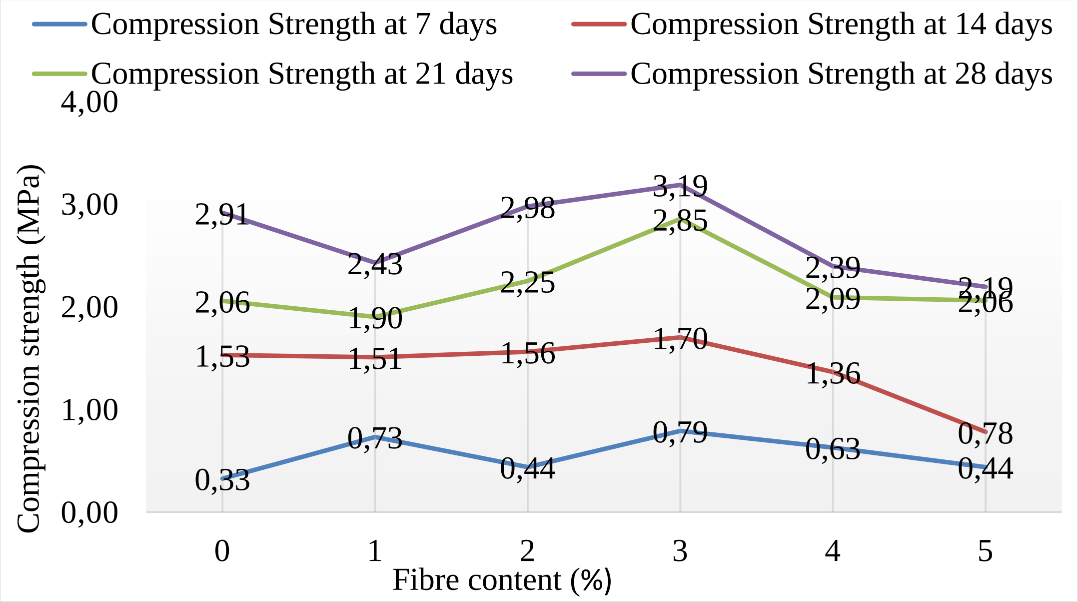


Figure 4.6: Compressive strength of blocks stabilized with 3% of cement and reinforced with various proportions of N-PALF.

4.5.2 Compressive strength of blocks stabilized with 3% of cement and reinforced with various proportions of T-PALF

The relationship between the compressive strength of blocks stabilized with 3% cement and various proportions of T-PALF are shown in Figure 4.7. As in Figure 4.6, it can be seen that the compressive strength of the reinforced blocks with T-PALF increased with increase of fibre content up to 3%, thereafter it decreased. According to the ACI Material, Journal Committee all the compressive strengths of the blocks reinforced with 0 to 5% of fibre content at 21 and 28 days of curing met the minimum threshold of 1.72 MPa. Similarly, the blocks with 2 to 4% of fibre content at 14 days of curing met this minimum threshold. The results also show that the compressive strengths of 3.81 and 4.01 MPa corresponded to 3% fibre content at 21 and 28 days of curing, respectively, hence, according to Tanzania Standard 283:1986 (TZS 283:1986) this mixture can be used for load bearing walls.

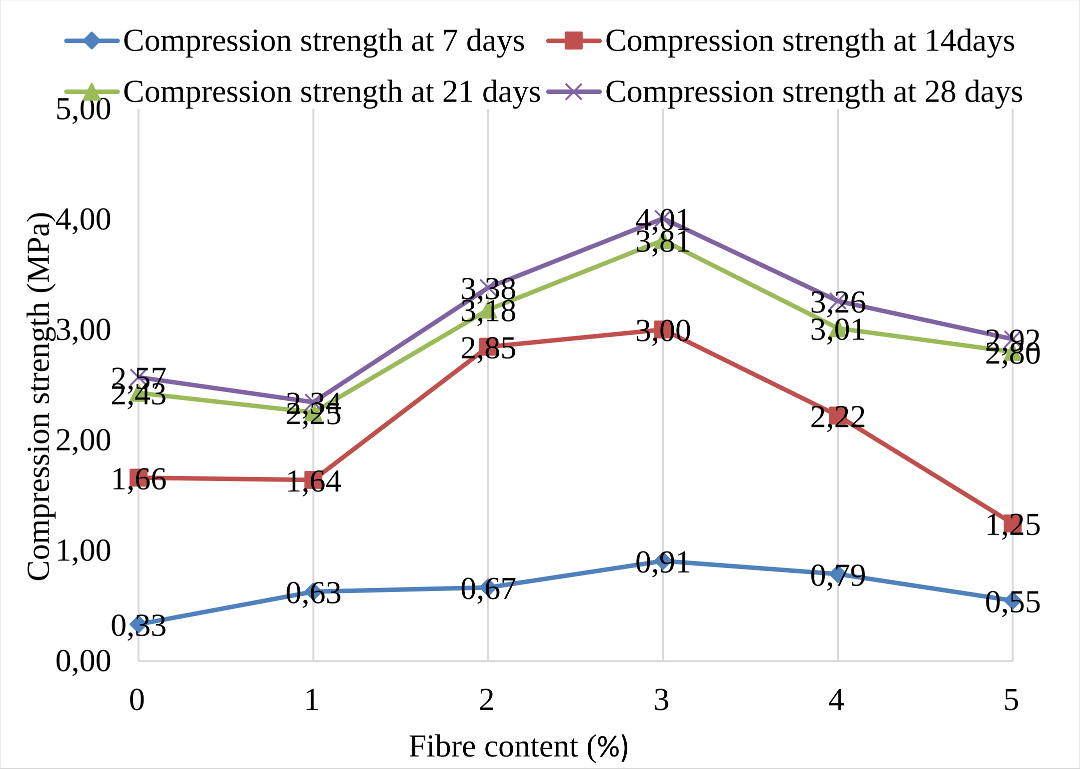


Figure 4.7: Compressive strength of blocks stabilized with 3% of cement and reinforced with various proportions of T-PALF.

4.5.3 Compressive strength of blocks stabilized with 5% of cement and reinforced with various proportions of N-PALF

Figure 4.8 shows the relation between the compressive strength of blocks stabilized with 5% cement and various proportions of N-PALF. As above the compressive strength increased with increase of fibre content up to 3% fibre content, thereafter it decreased. All the compressive strengths of the blocks reinforced with 0 to 5% of fibre content at 14 to 28 days of curing met the minimum threshold according to the ACI Material, Journal Committee. According to ASTM International E2392/E2392M-10e1 (2010) at 14 days of curing the blocks with 1 to 5% of fibre content met the minimum strength. The results also show that the compressive strengths of 3.58 MPa corresponding to 2% fibre content at 28 days of curing while 4.41 and 4.63 MPa corresponding to 3% fibre content at 21 and 28 days of curing, respectively, can also be used for load bearing walls.

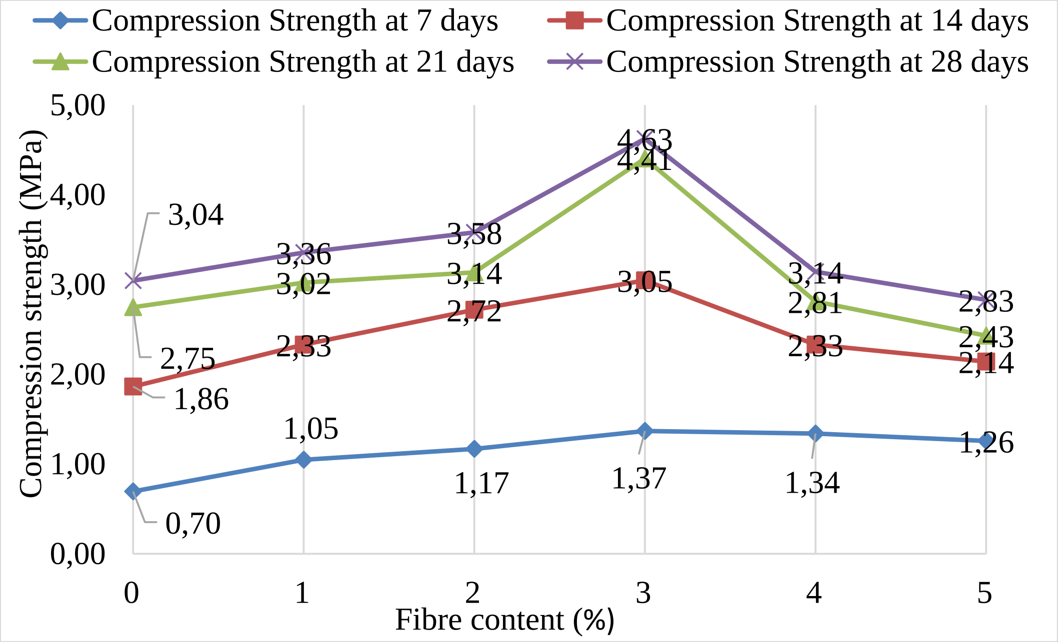


Figure 4.8: Compressive strength of blocks stabilized with 5% of cement and reinforced with various proportions of N-PALF

4.5.4 Compressive strength of blocks stabilized with 5% of cement and reinforced with various proportions of T-PALF

The results for relationship between the compressive strength of blocks stabilized with 5% cement and various proportions of T-PALF are presented in Figure 4.9. As above the compressive strength increased with increase of fibre content up to 3%, thereafter it decreased. All the compressive strengths of the blocks reinforced with 0 to 5% of fibre content at 14 to 28 days of curing met the minimum threshold according to the ACI Material, Journal Committee. It is also observed that at 7 days of curing the blocks with 3% of fibre content met minimum threshold. According to ASTM International E2392/E2392M-10e1 (2010) at 14 days of curing the blocks with 1 to 4% of fibre content met the minimum strength, in the similar way at 21 and 28 days of curing all the blocks met the minimum strength required by this standard. The results also show that load bearing walls can also be made from blocks with 1 to 3% fibre content at 21 and 28 days of curing, and 3% fibre content and 14 days of curing as the compressive strengths obtained ranged from 3.50 to 4.81 MPa, according to Tanzania Standard 283:1986 (TZS 283:1986).

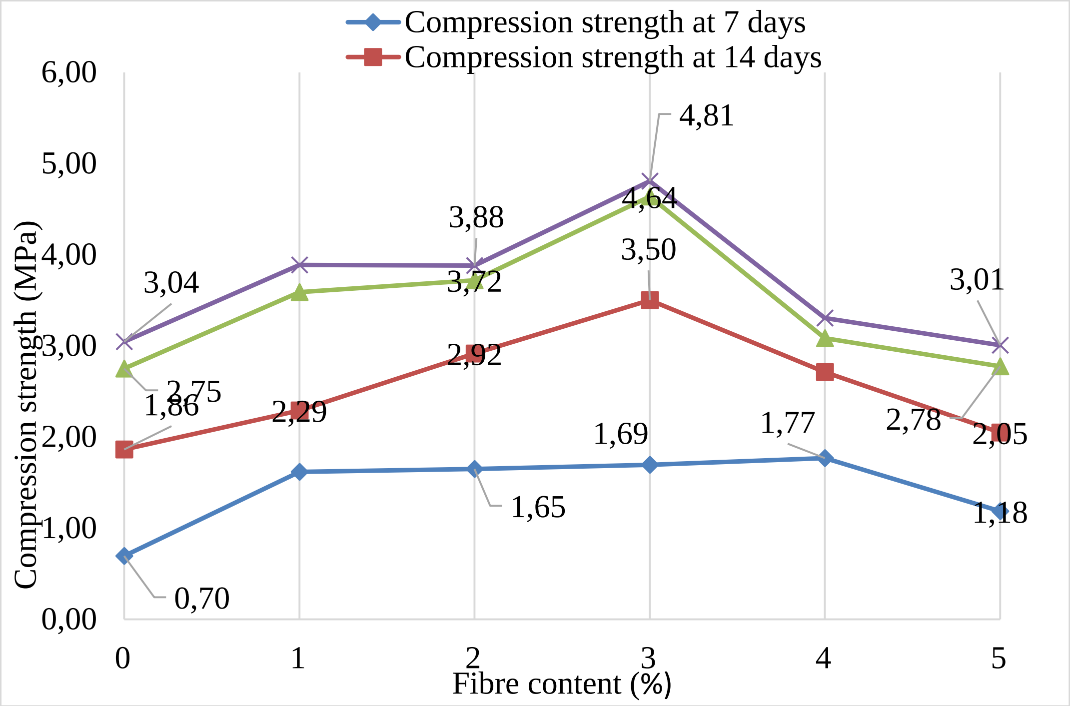


Figure 4.9: Compressive strength of blocks stabilized with 5% of cement and reinforced with various proportions of T-PALF.

4.5.5 Discussion of compressive strength results

Through the four groups of the blocks above, the compressive strength increased with fibre content because the fibres carried the load within the blocks but after 3% of fibre content, the compressive strength started decreasing because the fibres became a lot in the blocks and instead of reinforcing the blocks they started sticking together, making a ball up as waste material within the blocks and all these made the blocks to lose their strength. Similar observation was made (Danso, 2017; Ismail et al., 2011; (Danso et al., 2015)Danso et al., 2015). At the normal percentage of fibre within the soil particle, the fibres are able to carry the compressive strength load subjected to blocks.

By observing the strength of the blocks, it was observed that the T-PALF withstood the stresses within the blocks under compressive strength better than the N-PALF. This is due to the fact that sodium hydroxide treatment improved the tensile strength of the fibres and this improvement allowed the treated fibres to boost the strength of the blocks compared to those reinforced with non-treated fibres. A similar observations were made by Luma et al. (1996), and a significant improvement in the tensile strength was observed for polyester composites reinforced with treated PALF (Luma et al., 1996). This increase of strength with T-PALF is due to the action in traction of the fibre within the blocks by withstanding the blocks particles together under compression load. Furthermore, at the failure state of soil matrix the T-PALF were able to carry the compressive load better than the N-PALF.

4.5.6 Failures mode of blocks under compressive load

Figure 4.10 shows the failure mode of the blocks under compressive strength test. The results show that the unreinforced blocks had brittle failure while the reinforced ones had cracked failure. The fibre had made the blocks to become more ductile, more flexible, and more elastic, and all these made the blocks to resist against brittle failure. From Figure 4.10 (a) it can be seen that the blocks has extended in the wide direction, under compressive test. This was due to the fact that under compressive loading the fibres held together the soil particles against brittle failure. In addition; also the fibres prevent the blocks against crack's propagation. The cracks appeared because the fibres reached the maximum failure load which they could carry after failure of the soil matrix. Furthermore, the crack appeared because the stress-strain curve of the blocks under compressive loading started becoming nonlinear. In Figure 4.10(b) there were no fibres to carry the load, hence the failure mode was brittle at optimum loading.

(a) Reinforced block (b) Unreinforced block

Figure 4.10: Failure modes of reinforced and unreinforced blocks under compression.

4.6 Flexural Strength of the Blocks

In Figure 4.11 it can be seen that under flexural load, the reinforced blocks have a ductile behaviour with small crack at failure while the unreinforced blocks have a brittle failure in two stages. The fibres made the blocks to be more flexible under flexure load by bearing the traction action within the blocks. Figure 4.12 on the other hand shows that the flexural strength of the blocks increased with increase of fibre content up to 3% of fibre content, afterward it decreased. This observation was made in previous similar studies. For example, the flexural strength of pressed adobe blocks reinforced with Hibiscus Cannabinus fibres increased and then decreased with high content of fibre (Millogo et al., 2014). Table 4.4 shows the percentage of increase of reinforced blocks with each percentage of fibre content compare to unreinforced blocks.

(a) Reinforced (b) Non-reinforced

Figure 4.11: Mode of flexural failure for reinforced non-reinforced blocks.

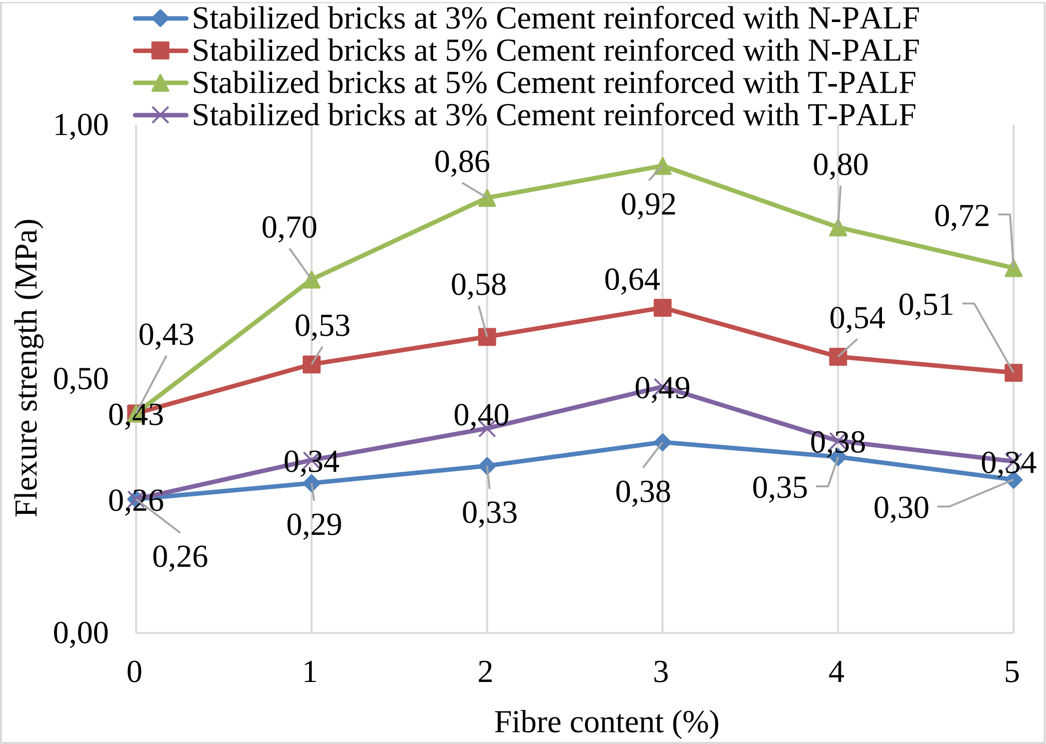


Figure 4.12: Flexure strength for reinforced blocks after 28 days.

The flexural strength for blocks reinforced with T-PALF was higher than that for blocks reinforced with N-PALF. At the optimum fibre content (3% of PALF) the flexural strength of the stabilized blocks with 5% of cement were 0.64 and 0.92 MPa, respectively, for blocks reinforced with N-PALF and T-PALF, while for the control block it was 0.43MPa. Therefore, there was an increase of 48.8 and 114.0%, respectively, with N-PALF and T-PALF when compared with the unreinforced blocks. In the same manner, at the optimum fibre content (3% of PALF) the flexural strength of stabilized blocks with 3% of cement were 0.38 and 0.49 MPa, respectively, for blocks reinforced with N-PALF and T-PALF, while for the control block had 0.26 MPa. Hence, there was an increase of 46.2 and 88.5%, respectively, with N-PALF and T-PALF when compared with the unreinforced blocks. The T-PALF have more restricted crack tip propagation more than N-PALF and this led to increase in the flexural strength of the blocks reinforced with T-PALF than with N-PALF.

Table 4.4: Percentage increase in flexural strength

	Percentage increase when compared to unreinforced blocks			
Mix with:	3 N-PALF	3 T-PALF	5 N-PALF	5 T-PALF
1 % of Fibre	11,90	29,11	22,36	60,99
2 % of Fibre	24,94	52,91	34,93	98,15
3% of Fibre	42,53	84,18	48,19	112,80
4% of Fibre	31,65	43,54	25,83	84,66
5% of Fibre	14,56	28,23	18,50	66,23

In the table: 3N-PALF is blocks stabilized with 3% cement and reinforced with N-PALF; 3T-PALF is blocks stabilized with 3% cement and reinforced with T-PALF , similarly for 5T-PALF and 5N-PALF

On the other hand, with blocks stabilized with 5% of cement the T-PALF increased the flexural strength by more than double for those for N-PALF. With the blocks stabilized with 3% of cement the T-PALF increased the flexural strength by about double of that for N-PALF. The T-PALF increased the strength of the blocks in flexure more than in compression. This shows that the fibre acted more in traction than in compression within the composite as the case with steel reinforcement in concrete beam. Finally, the best fibre content in the blocks is with 5% of cement.

4.7 Splitting Tensile Strength

Splitting tensile strength was used to assess the tensile strength of brittle materials as mortar, because direct tensile test cannot be done on such types of materials. The summary of the splitting tensile strength test result is presented in Figures 4.13 and 4.14. The results show that the splitting tensile strength increased with increase of fibres content but after 3% fibre content it start decreased. The strength decreased because the high content of fibre in the blocks made a balling up which caused the blocks to loose strength. For both blocks stabilized with 3 and 5% and reinforced with treated and untreated fibres, it was observed that the treated fibre had significantly improved the tensile strength when compared to those reinforced with untreated fibres. This is because the sodium hydroxide treatment increased the tensile strength of the fibres and this lead to the increase of the tensile strength of the blocks. In Figure 4.13, it is observed that with 3% of fibre content there was increase of 62.5% of blocks reinforced with treated fibre over the untreated one, while in Figure 4.14 with 3% of fibre content there was increase of 66.7 of blocks reinforced with treated fibre over the untreated one.

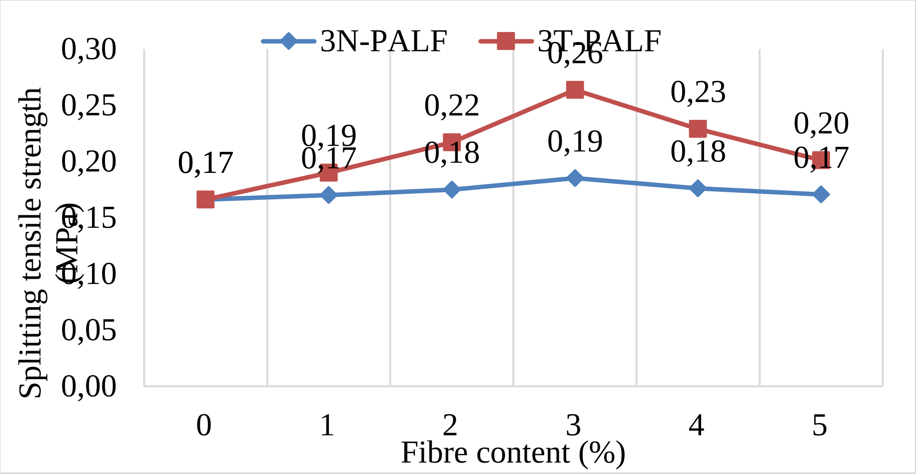


Figure 4.13: Tensile strength of 3% cement stabilized blocks reinforced with T-PALF and N-PALF.

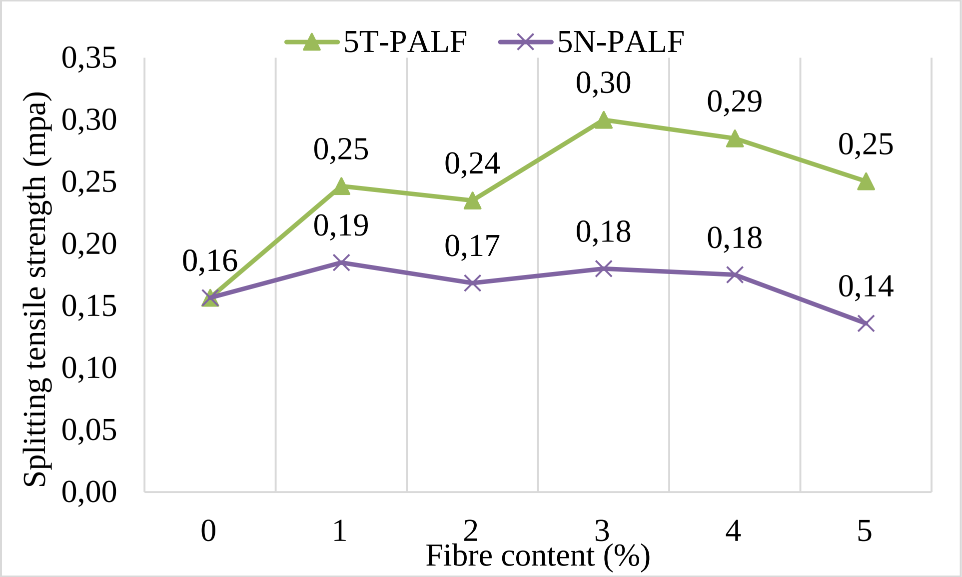


Figure 4.14: Tensile strength of 5% cement stabilized blocks reinforced with T-PALF and N-PALF.

4.8 Durability of the Blocks

4.8.1 Durability based on abrasion resistance

The results in Figure 4.15 show that abrasion resistance increase with an increase in fibre content up to 3% afterward it decreased. In addition, it was observed that the blocks stabilized with 5% of cement resisted against abrasion more than those reinforced with 3% of cement. Furthermore, the blocks reinforced with treated fibres had higher abrasion resistance as compared to non-treated ones. According to Yan et al. (2012), the treated fibres were able to increase abrasion index as the sodium hydroxide treatment makes the surface of the fibre to become rough.

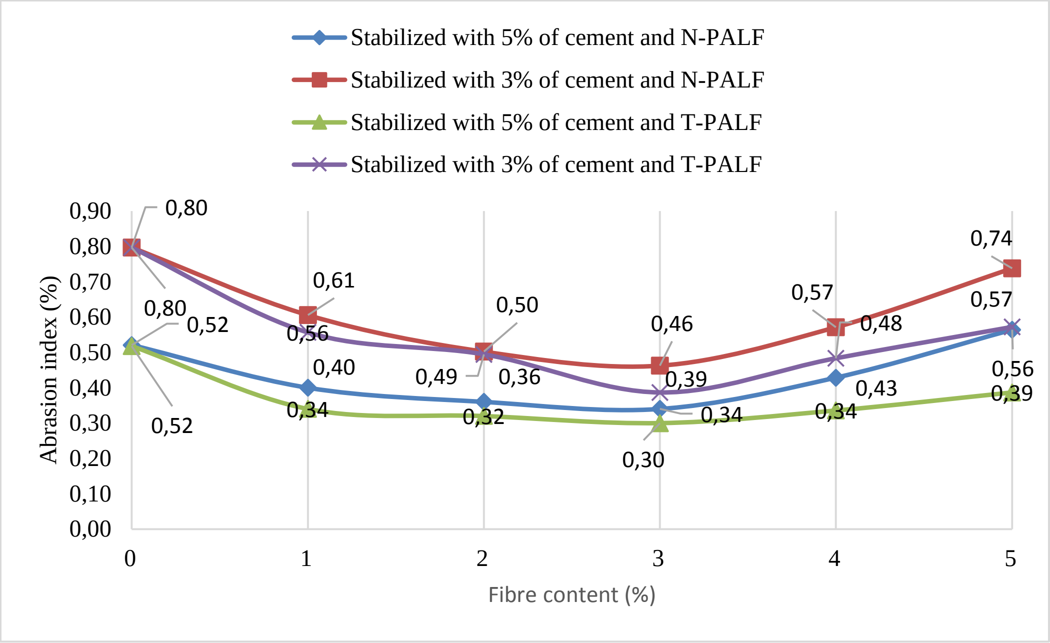


Figure 4.15: Abrasion resistance of reinforced blocks with increase in fibre content.

4.8.2 Earth block drop test result

All the block samples, 45 in number, passed the earth drop test according to New Zealand Standard NZS 4298:1998. This standard states that the block shall pass if it does not break into approximately equally sized pieces nor shall there be missing from the largest remaining piece 100 mm or greater from any corner.

4.9 Physical Properties of the Blocks

4.9.1 Dry density

The results in Figure 4.16 show that the dry density of the blocks ranged between 1827.3 and 2074.0 kg/m^3. It is also observed that the densities of blocks stabilized with 5% of cement are higher than those stabilized with 3% of cement, this happened because of packing density (the fraction of a volume filled by a given collection of solids), in this study 5% of cement filled better the empties spaces in the blocks compare to those stabilize with 3% of cement, hence 5% of cement has increased the density of the blocks. A similar observation has been made by (Raj, Mohammad et al.2017) in which the density of earth stabilize blocks increase with increase in cement content. On the other hand, it was also observed that the density of the blocks decreased with increase in fibre content. The density was higher for blocks reinforced with treated fibres as compared to those reinforced with non-treated fibres. This may be explained by the hydrophilic properties of the fibre because the treated fibre absorbed less water comparing to non-treated ones. According to (Sampathkumar et al., 2012) alkali treatment improves the water absorption of areca fibres, so after curing they created more space within the block hence its weight becomes lighter than those reinforced with treated fibres.

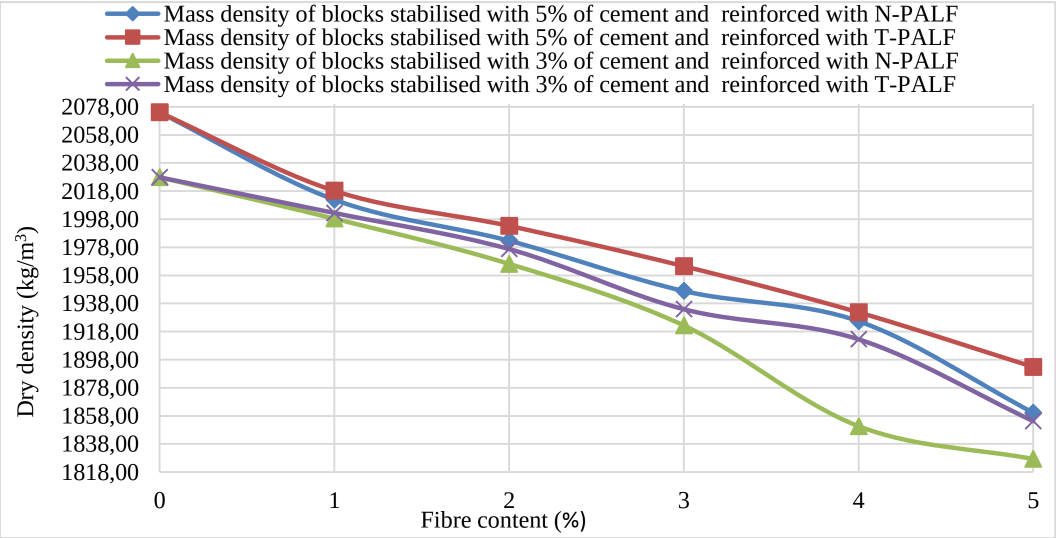


Figure 4.16: Relation between dry density of blocks with increase in fibre content.

4.9.2 Water absorption ability

Figure 4.17 and Figure 4.18 present the water absorption of the blocks and the result show that of all the cement stabilize blocks reinforced with T-PALF absorbed less water as comparing to those reinforced with N-PALF and this is because the T-PALF absorbed less water than N-PALF. By comparing both results in Figure 4.17 and in Figure 4.18, it was observed that the stabilized blocks with 5% of cement absorbed less water compared to those stabilize with 3% of cement. It is then important to notice that 5% of cement is best rate for soil block because with 5% of cement the chemical reaction between the cement and soil particles is higher and this allows a good bondage between the soil particles, hence it absorbs less water. For instance, (Egenti et al., 2015) found that the water absorption of laterite blocks decreased with increase of cement content.

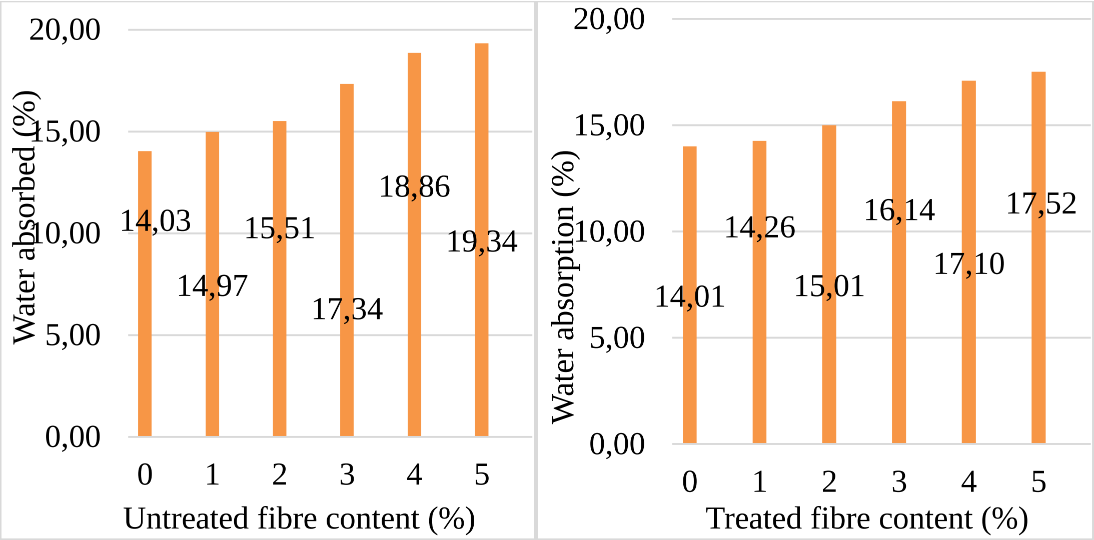


Figure 4.17: Water absorption for blocks stabilized with at 3% of cement and reinforced with N-PALF and T-PALF.

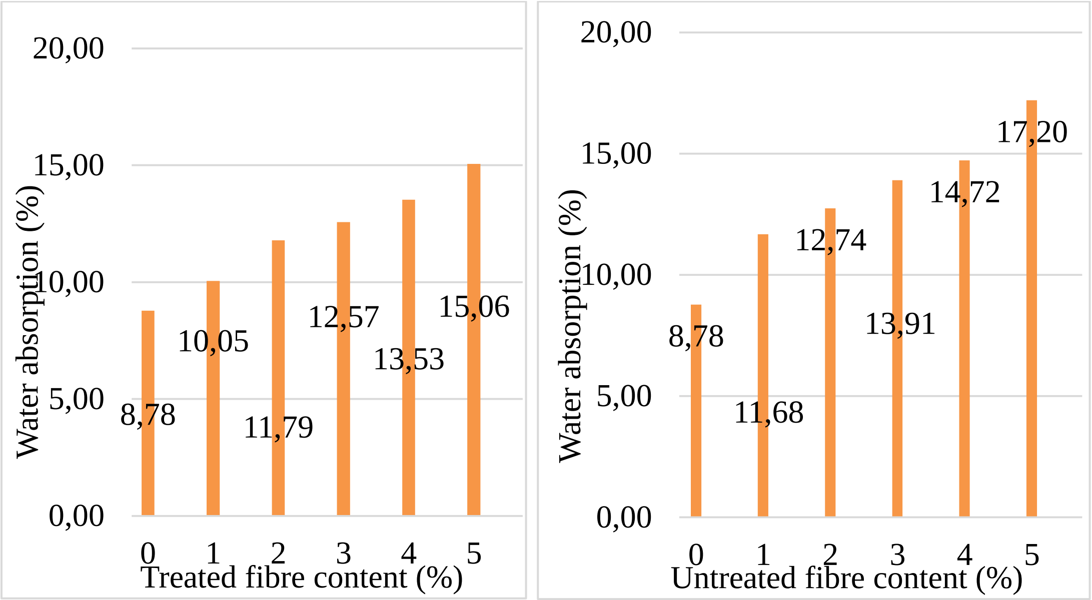


Figure 4.18: Water absorption for blocks stabilized with at 5% of cement and reinforced with T-PALF and N-PALF.

4.10 Cost Benefit Analysis

4.10.1 Cost analysis

For cost analysis, the costs of different materials used to make the blocks were computed then added together. The analysis of different unit cost of the blocks according to either the materials was free or bought are presented below. These costs were compared to the cost of fired clay blocks (manufactured at Kenya Clay Products Ltd, Ruiru) which the unit price is Ksh 35 per block, and the interlocking block cost Ksh 29.4 (Pigiame, 2018).

It was observed that the compressive strength of the clay burnt blocks was 5.069 MPa and interlocking blocks was from 7 to 10 MPa while the highest compressive strength of the cement stabilized reinforced block was 4.81 MPa and that value was obtained with the blocks stabilized with 5% of cement reinforced with treated fibre. In the following steps, different cases of cost analysis study are presented.

a) All materials are assumed to have been bought

Table 4.5 shown that reinforced block stabilized with 5% cement are more expensive than both interlocking and fired clay block, but the reinforced blocks stabilized with 3% cement are beneficial. However, the blocks reinforced with treated fibre and stabilized with 3% cement were found to be more expensive of about 1.7% while comparing to interlocking blocks. These results are for the case that all the materials were bought, let’s move on for the case where the soil are for free.

Table 4.5: Comparative analysis of the cost of available walling materials per metre square of walls in Kenya when all the materials were bought

Items	Interlocking block	Fired Clay block	5% cement stabilized blocks reinforced with:			3% cement stabilized blocks reinforced with:		
			T-PALF	0-PALF	N-PALF	T-PALF	0-PALF	N-PALF
No of blocks per m2 of wall	37	32	24	24	24	24	24	24
Unit cost of block (Ksh)	29,4	35	54,80	19,24	52,51	39,47	16,97	37,18
Cost of blocks /m2 of wall (Ksh)	1087,8	1120	1315,15	461,9	1260,3	947,2	407,3	892,3
Cost of bonding mortar /m2 of wall	0	100,8	158,8	158,8	158,8	158,8	158,8	158,8
Total cost of a m2 of wall (N)	1087,8	1220,8	1473,9	620,62	1419,1	1106	566,14	1051,12
Compressive strength (N/mm2)	**8,5**	**5.069**	**4.81**	**3.04**	**4.63**	**4.01**	**2.91**	**3.19**
Savings (+) or losing (-) in cost compared to Fired Clay Blocks (%)			**-20,7**	**49,2**	**-16,2**	**9,4**	**53,6**	**13,9**
Savings (+) or losing (-) in cost compared to interlocking blocks (%)			**-35,5**	**42,9**	**-30,5**	**-1,7**	**48,0**	**3,4**

0-PALF*; non-reinforced block

b) The soil assumed to be free

The results of Table 4.6 show that reinforced blocks stabilized with 5% of cement are not beneficial if the soil is free as comparing to fired clay block. In contrary the reinforced blocks stabilized with 3% of cement are all beneficial.

Table 4.6: Comparative analysis of the cost of available walling materials per metre square of walls in Kenya when the soil assumed to be free

Items	Interlocking block	Fired Clay block	5% cement stabilized blocks reinforced with:			3% cement stabilized blocks reinforced with:		
			T-PALF	0-PALF	N-PALF	T-PALF	0-PALF	N-PALF
No of blocks per m2 of wall	37	32	24	24	24	24	24	24
Unit cost of block (Ksh)	29,4	35	52,10	16,54	49,81	36,77	14,27	34,48
Cost of blocks /m2 of wall (Ksh)	1087,8	1120	1250,35	397,06	1195,5	882,38	342,55	827,52
Cost of bonding mortar /m2 of wall	0	100,8	158,75	158,76	158,77	158,78	158,79	158,8
Total cost of a m2 of wall (N)	1087,8	1220,8	1409,1	555,82	1354,3	1041,2	501,34	986,32
Compressive strength (N/mm2)	**8,5**	**5.069**	**4.81**	**3.04**	**4.63**	**4.01**	**2.91**	**3.19**
Savings (+) or losing (-) in cost compared to Fired Clay Blocks (%)			**-15,4**	**54,5**	**-10,9**	**14,7**	**58,9**	**19,2**
Savings (+) or losing (-) in cost compared to interlocking blocks (%)			**-29,537**	**48,904**	**-24,495**	**4,2878**	**53,913**	**9,32892**

c) The fibre is assumed to be free

The results of Table 4.7 show that in the case where the fibres are free, all the reinforced stabilized blocks are beneficial. It becomes important to have a local pineapple leave extractor machine available in the way to make this fibre available at cheap price.

Table 4.7: Comparative analysis of the cost of available walling materials per metre square of walls in Kenya when the fibre is assumed to be free

Items	Interlocking block	Fired Clay block	5% cement stabilized blocks reinforced with:			3% cement stabilized blocks reinforced with:		
			T-PALF	0-PALF	N-PALF	T-PALF	0-PALF	N-PALF
No of blocks per m2 of wall	37	32	24	/	24	24	/	24
Unit cost of block (Ksh)	29,4	35	21,53	/	19,24	19,26	/	16,97
Cost of blocks /m2 of wall (Ksh)	1087,8	1120	516,72	/	461,86	462,21	/	407,349
Cost of bonding mortar /m2 of wall	0	100,8	158,75	/	158,77	158,78	/	158,8
Total cost of a m2 of wall (N)	1087,8	1220,8	675,47	/	620,63	620,99	/	566,149
Compressive strength (N/mm2)	**8,5**	**5.069**	**4.81**	/	**4.63**	**4.01**	/	**3.19**
Savings (+) or losing (-) in cost compared to Fired Clay Blocks (%)			**44,7**	/	**49,2**	**49,1**	/	**53,6**
Savings (+) or losing (-) in cost compared to interlocking blocks (%)			**37,9**	/	**42,9**	**42,9**	/	**48,0**

0-PALF*; non-reinforced block

4.10.2 Graphical illustration of Unit prices of the blocks

In Figure 4.19, it was shown graphically the unit cost of the blocks. The cost of blocks stabilized with 5% cement and reinforced with T-PALF was found to be the most expensive one, while the blocks stabilized with 3% cement was the cheapest one. It is also important to mention that the cost of the blocks for the case that the fibres are free is beneficial.

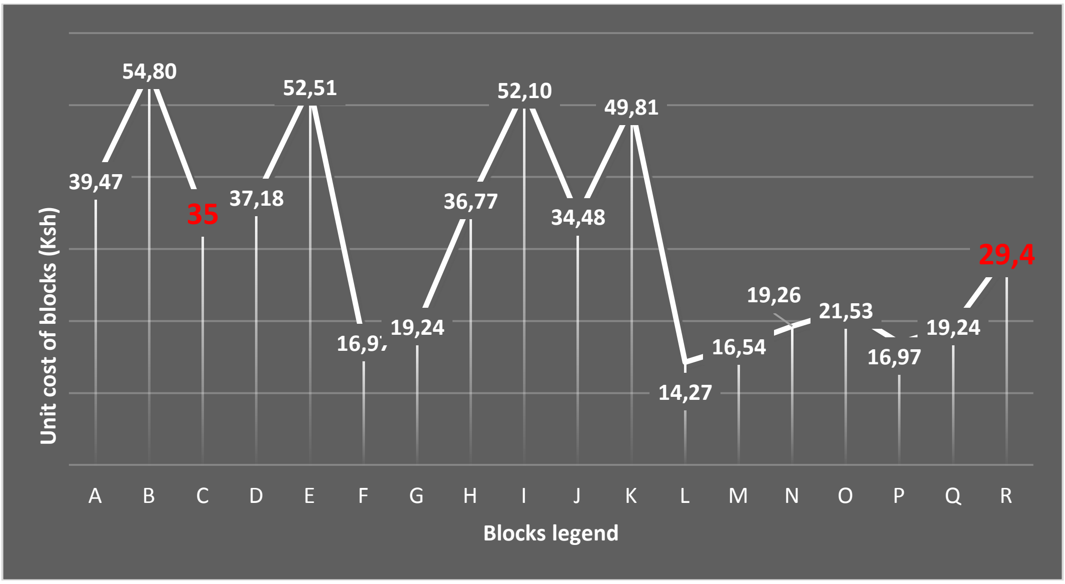


Figure 4.19: Graphical illustration of Unit prices of the blocks

Legends:

All materials are assumed to be bought:
(A) Blocks stabilized with 3% cement and reinforced with T-PALF

(B) Blocks stabilized with 5% cement and reinforced with T-PALF

(D) Blocks stabilized with 3% cement and reinforced with N-PALF

(E) Blocks stabilized with 5% cement and reinforced with N-PALF

(F) Blocks stabilized with 3% cement

(G) Blocks stabilized with 5% cement

The soil is assumed to be free:
(H) Blocks stabilized with 3% cement and reinforced with T-PALF

(I) Blocks stabilized with 5% cement and reinforced with T-PALF

(J) Blocks stabilized with 3% cement and reinforced with N-PALF

(K) Blocks stabilized with 5% cement and reinforced with N-PALF

(L) Blocks stabilized with 3% cement

(M) Blocks stabilized with 5% cement

The soil is assumed to be free:

(N) Blocks stabilized with 3% cement and reinforced with N-PALF

(O) Blocks stabilized with 5% cement and reinforced with N-PALF

(P) Blocks stabilized with 3% cement and reinforced with T-PALF

(Q) Blocks stabilized with 5% cement and reinforced with T-PALF

(C) Clay block

(R) Interlocking block

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This study investigated the compressive strength of blocks stabilized with 3 and 5% of cement and reinforced with non-treated and treated pineapple leaf fibres. The results show that:

i) The laterite soil that was used had high contents of clay (20%) and silt (20%) which not suitable for making good blocks. For this reason some sand was added to reduce the dominance of clay as this would lead to excessive drying shrinkage, and reduced durability and compressive strength. The soil was found to be laterite as the silica sesquioxides ratio (SiO2/ [Al2O3+Fe2O3]) was equal to 1.5. The amount of cellulose, hemicellulose and lignin in the fibres decreased with increase in duration of treatment with sodium hydroxide solution. In addition, the treatment increased the tensile strength of the fibres up to an optimum value of 766.9 MPa after 106.8 minutes. Finally, the aspect ratio of treated and non-treated pineapple leaf fibres were 243.9 and 185.2, respectively and these found to be out of the recommended.

ii) The compressive strength of the fibre reinforced blocks increased with increase in fibre content up to 3%, thereafter it decreased. At 3% cement stabilization, 3% of treated fibres and 21 to 28 days of curing, the blocks attained enough compressive strength for construction of load bearing walls. However, better performance was obtained for 5% cement stabilized blocks at 3% fibre content. The blocks reinforced with sodium hydroxide treated fibres had higher compressive strength than non-treated fibres. It was also observed that the water absorption of the blocks increased with increase in fibre content. However, blocks reinforced with the non-treated fibres absorbed more water than those with treated fibres. The abrasion test indicated that the block resist abrasion with increase in fibre content up to 3% fibre beyond which the abrasion decreased.

iii) Cost benefit analysis shown that in the case which all the materials are assumed to be bought, with the blocks stabilized with 5%cement and reinforced with T-PALF there are lost per meter square of about 20.7% and 35.5% respectively to fired clay block and interlocking block . On the other hand, in the case which the fibre is free, with the blocks stabilized with 5%cement and reinforced with T-PALF there are lost per meter square of about 44.7% and 37.9% respectively to fired clay block and interlocking block.

5.2 RECOMMENDATIONS

From the study the following recommendations are made:

(i) As cement stabilized blocks reinforced with sodium hydroxide treated fibres had less water absorption capacity than non-treated ones, it is recommended that the treated blocks used for external walls while the non-treated ones be used for internal walls.

(ii) Since the fibres used in this study were procured from India, their cost was high rendering the cost of the blocks to be high. It is recommended that mechanisms be put in place to produce such fibres locally in order to reduce its cost and eventually the cost of the blocks.

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APPENDICES

APPENDICES

APPENDICE 1: Cost analysis

Table A1: Cost estimation of the blocks when all the materials are supposed to have been bought

3% cement stabilized blocks reinforced with T-PALF (A)					5% cement stabilized blocks reinforced with T-PALF (B)				
MATERIAL	**QUANTITY**	**UNIT**	**COST IN Ksh**	**TOTAL COST IN Ksh**	**MATERIAL**	**QUANTITY**	**UNIT**	**COST IN Ksh**	**TOTAL COST IN Ksh**
Cement	10,25	Kg	123	123	Cement	16,875	Kg	202,5	202,5
Soil	236,25	Kg	94,5	94,5	Soil	236,25	Kg	94,5	94,5
River sand	84,375	Kg	126,55	126,55	River sand	84,375	Kg	126,55	126,55
PALF	0,3075	kg	707,25	707,25	PALF	0,50625	kg	1164,375	1164,375
Sodium Hydroxide	80	g	80	80	Sodium Hydroxide	80	g	80	80
Labour	Half day	Day	250	250	Labour	Half day	Day	250	250
TOTAL COST FOR 35				1381,3	TOTAL COST FOR 35				1917,925
Price of one block				39,47	Price of one block				54,80
3% cement stabilized blocks reinforced with N-PALF (D)					**5% cement stabilized blocks reinforced with N-PALF (E)**				
Cement	10,25	Kg	123	123	Cement	16,875	Kg	202,5	202,5
Soil	236,25	Kg	94,5	94,5	Soil	236,25	Kg	94,5	94,5
River sand	84,375	Kg	126,55	126,55	River sand	84,375	Kg	126,55	126,55
PALF	0,3075	kg	707,25	707,25	PALF	0,50625	kg	1164,375	1164,375
Labour	Half day	Day	250	250	Labour	Half day	Day	250	250
TOTAL COST FOR 35				1301,3	TOTAL COST FOR 35				1837,925
Price of one block				37,18	Price of one block				52,51
unreinforced 3% cement stabilized blocks (F)					**unreinforced 5% cement stabilized blocks (G)**				
Cement	10,25	Kg	123	123	Cement	16,875	Kg	202,5	202,5
Soil	236,25	Kg	94,5	94,5	Soil	236,25	Kg	94,5	94,5
River sand	84,375	Kg	126,55	126,55	River sand	84,375	Kg	126,55	126,55

Labour	Half day	Day	250	250	Labour	Half day	Day	250	250
TOTAL COST FOR 35				594,05	TOTAL COST FOR 35				673,55
Price of one block				16,97	Price of one block				19,24

Table A2: Cost estimation of the blocks when the soil assumed to be free

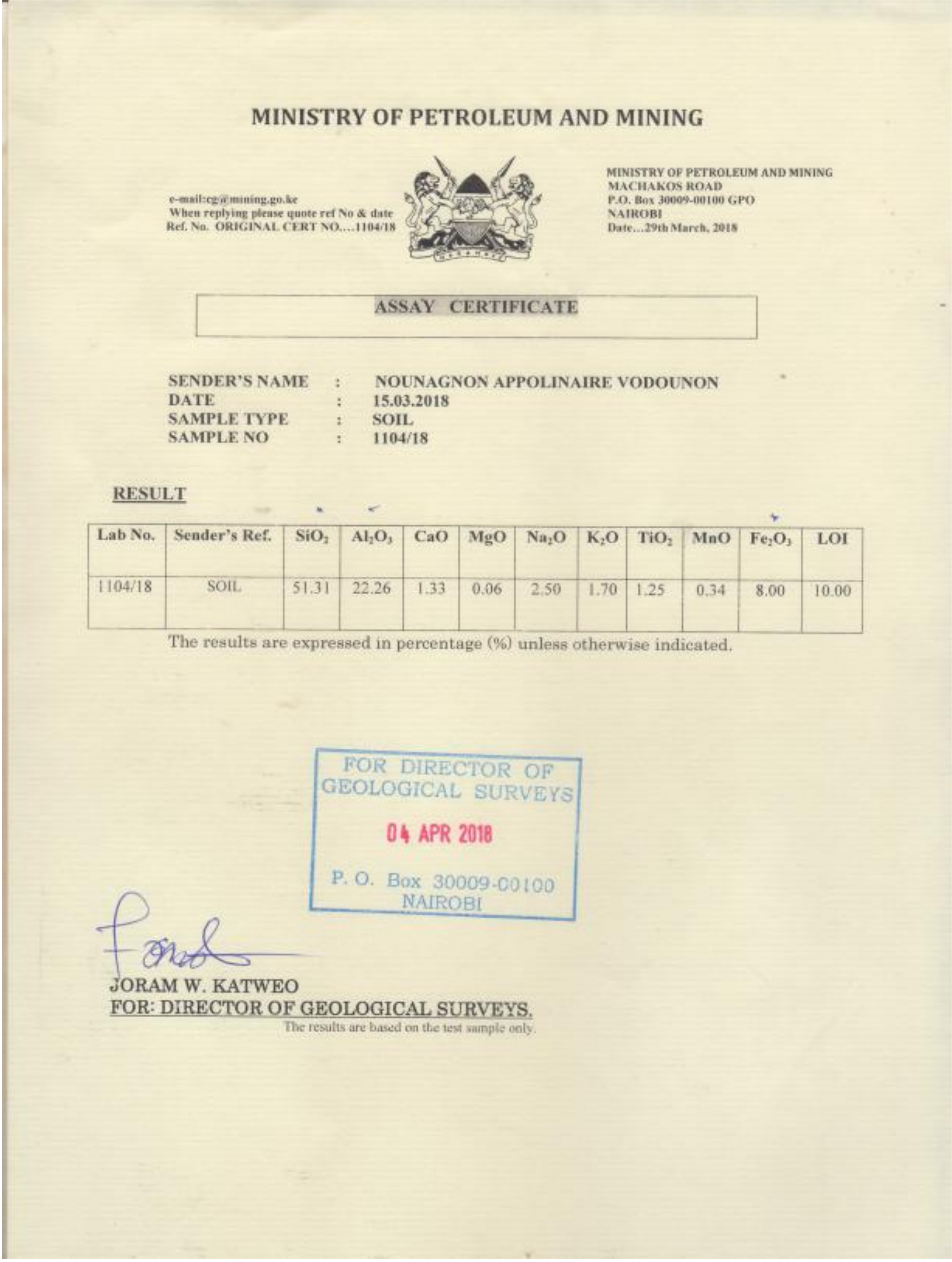
3% cement stabilized blocks reinforced with T-PALF (H)					**5% cement stabilized blocks reinforced with T-PALF (I)**				
MATERIAL	**QUANTITY**	**UNIT**	**COST IN Ksh**	**TOTAL COST IN Ksh**	**MATERIAL**	**QUANTITY**	**UNIT**	**COST IN Ksh**	**TOTAL COST IN Ksh**
Cement	10,25	Kg	123	123	Cement	16,875	Kg	202,5	202,5
Soil	236,25	Kg	0	0	Soil	236,25	Kg	0	0
River sand	84,375	Kg	126,55	126,55	River sand	84,375	Kg	126,55	126,55
PALF	0,3075	kg	707,25	707,25	PALF	0,50625	kg	1164,375	1164,375
Sodium Hydroxide	80	g	80	80	Sodium Hydroxide	80	g	80	80
Labour	Half day	Day	250	250	Labour	Half day	Day	250	250
TOTAL COST FOR 35				1286,8	TOTAL COST FOR 35				1823,425
PRICE FOR ONE BLOCK				36,77	PRICE FOR ONE BLOCK				52,10
3% cement stabilized blocks reinforced with N-PALF (J)					**5% cement stabilized blocks reinforced with N-PALF (K)**				
Cement	10,25	Kg	123	123	Cement	16,875	Kg	202,5	202,5
Soil	236,25	Kg	0	0	Soil	236,25	Kg	0	0
River sand	84,375	Kg	126,55	126,55	River sand	84,375	Kg	126,55	126,55
PALF	0,3075	kg	707,25	707,25	PALF	0,50625	kg	1164,375	1164,375
Labour	Half day	Day	250	250	Labor	Half day	Day	250	250
TOTAL COST FOR 35				1206,8	TOTAL COST FOR 35				1743,425
PRICE FOR ONE BLOCK				34,48	PRICE FOR ONE BLOCK				49,81
unreinforced 3% cement stabilized blocks (L)					**unreinforced 5% cement stabilized blocks (M)**				
Cement	10,25	Kg	123	123	Cement	16,875	Kg	202,5	202,5
Soil	236,25	Kg	0	0	Soil	236,25	Kg	0	0
River sand	84,375	Kg	126,55	126,55	River sand	84,375	Kg	126,55	126,55

Labour	Half day	Day	250	250	Labor	Half day	Day	250	250
TOTAL COST FOR 35				499,55	TOTAL COST FOR 35				579,05
PRICE FOR ONE BLOCK				14,27	PRICE FOR ONE BLOCK				16,54

Table A3: Cost estimation of the blocks when the fibre is assumed to be free

3% cement stabilized blocks reinforced with T-PALF (P)					**5% cement stabilized blocks reinforced with T-PALF (Q)**				
MATERIAL	**QUANTITY**	**UNIT**	**COST IN Ksh**	**TOTAL COST IN Ksh**	**MATERIAL**	**QUANTITY**	**UNIT**	**COST IN Ksh**	**TOTAL COST IN Ksh**
Cement	10,25	Kg	123	123	Cement	16,875	Kg	202,5	202,5
Soil	236,25	Kg	94,5	94,5	Soil	236,25	Kg	94,5	94,5
River sand	84,375	Kg	126,55	126,55	River sand	84,375	Kg	126,55	126,55
PALF	0,3075	kg	0	0	PALF	0,50625	kg	0	0
Sodium Hydroxide	80	g	80	80	Sodium Hydroxide	80	g	80	80
Labour	Half day	Day	250	250	Labour	Half day	Day	250	250
TOTAL COST FOR 35				674,05	TOTAL COST FOR 35				753,55
PRICE FOR ONE BLOCK				19,26	PRICE FOR ONE BLOCK				21,53
3% cement stabilized blocks reinforced with N-PALF (N)					**5% cement stabilized blocks reinforced with N-PALF (0)**				
Cement	10,25	Kg	123	123	Cement	16,875	Kg	202,5	202,5
Soil	236,25	Kg	94,5	94,5	Soil	236,25	Kg	94,5	94,5
River sand	84,375	Kg	126,55	126,55	River sand	84,375	Kg	126,55	126,55
PALF	0,3075	kg	0	0	PALF	0,50625	kg	0	0
Labour	Half day	Day	250	250	Labour	Half day	Day	250	250
TOTAL COST FOR 35				594,05	TOTAL COST FOR 35				673,55
PRICE FOR ONE BLOCK				16,97	PRICE FOR ONE BLOCK				19,24

APPENDICE 2:Chemical analysis test result of soil



MINISTRY OF PETROLEUM AND MINING

e-mail:cg@mining.go.ke
When replying please quote ref No & date
Ref. No. ORIGINAL CERT NO....1104/18

MINISTRY OF PETROLEUM AND MINING
MACHAKOS ROAD
P.O. Box 30009-00100 GPO
NAIROBI
Date...29th March, 2018

ASSAY CERTIFICATE

SENDER'S NAME : **NOUNAGNON APPOLINAIRE VODOUNON**
DATE : **15.03.2018**
SAMPLE TYPE : **SOIL**
SAMPLE NO : **1104/18**

RESULT

Lab No.	Sender's Ref.	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	Fe_2O_3	LOI
1104/18	SOIL	51.31	22.26	1.33	0.06	2.50	1.70	1.25	0.34	8.00	10.00

The results are expressed in percentage (%) unless otherwise indicated.

FOR DIRECTOR OF
GEOLOGICAL SURVEYS
04 APR 2018
P. O. Box 30009-00100
NAIROBI

JORAM W. KATWEO
FOR: DIRECTOR OF GEOLOGICAL SURVEYS.
The results are based on the test sample only.