KYAMBOGO UNIVERSITY

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INVESTIGATION OF THE EFFECTS OF RICE HUSK AND RICE STRAW ON THE PROPERTIES OF LIGHTWEIGHT FIBRECRETE BLOCKS

BY

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A RESEARCH DISSERTATION SUBMITTED TO KYAMBOGO UNIVERSITY GRADUATE SCHOOL IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTERS OF SCIENCE IN STRUCTURAL ENGINEERING DEGREE OF KYAMBOGO UNIVERSITY

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CERTIFICATION

The undersigned certify that, they have read and hereby recommend for acceptance by Kyambogo University a dissertation entitled: ''*Investigation of the Effects of Rice Husk and Rice straw on the Properties of Lightweight Fibrecrete Blocks*''. This research has been accomplished under our supervision and is ready for submission to Kyambogo University Graduate School in partial fulfilments for the award of Master of Science in Structural Engineering degree of Kyambogo University.

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DECLARATION

I ABAZA LEO, hereby declare that this submission is my own work and that, to the best of my knowledge and belief. It contains no material previously published or written by another person nor material which has been accepted for the award of any other degree of the University or other Institute of higher learning, except where due acknowledgement has been made in the text and reference list.

Signed ....Ab[signature]....

Date ....6|10|2022....

DEDICATION

I dedicate this research dissertation to my daughter Alesi Precious Leo and to the entire family of Late Hillary Amagu and Emma Amabayo.

ACKNOWLEDGEMENT

My most humble appreciation to God for protecting me during the study period by providing an enabling environment and good health. I also thank the Lord for the strength, wisdom, grace and every provision.

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May the Almighty God bless you all?

ABSTRACT

Uganda's progress towards achieving sustainable growth is curtailed by poor and limited infrastructure, over 60% of town population live in shantytowns with deprived quality accommodation and sanitation, 44% of households sleep in one room, the situation is dire in Kampala where about 70% sleep in one room. About 67 % of Ugandans live in dwellings with brick walls while 28 % live in dwellings of mud walls reinforced with timber poles. Over 90 % of framed structure in Uganda are built from reinforced concrete structures with bricks/ block infill walls that are heavy thus influencing the type and size of structural members. Lightweight building materials are in the neighbourhood and plentifully available, their efficient use in developing decent housing is quite challenging as they are largely unprocessed, underdeveloped and un-standardised, limiting their prospective. This research focused on use of Rice Husks (RH) and Rice Straws (RS) in lightweight fibrecrete blocks for benefit of their reduced weight. In this research, the fibres were alkali-treated using sodium hydroxide solution prepared by dissolving 15g of the pellets in 1liter of water heated at 100°C for 60 minutes to create surface roughness, expose cellulose to fibre surface and improve fibre/matrix adhesion. The fibres were then used to prepare 121 fibrecrete blocks of 400x150x200mm dimensions with varying proportions of 0%, 10%, 20%, 30%, 40%, and 50% of RH and RS and tested for density, compressive strength, water absorption, thermal conductivity, fire resistances and microstructure. The densities of lightweight fibrecrete blocks ranged between (1947-1485) kg/m^3 with a reduction of (7.9- 30.5) % compared to control blocks. Compressive strength of the blocks varied between 1.53 - 5.36N/mm^2 for RH blocks and 1.28 - 3.48N/mm^2 for RS blocks at 28 days. The loss in compressive strength of lightweight fibrecrete blocks tested for fire resistance ranged from 10.7- 34.3% and 6.8-73.7% for RH and RS-blocks respectively while water absorption ranged between (5.8-7.8) % for RH and (6.4-11.3) % for RS blocks and 3.6% for control blocks. Thermal conductivity improved by (13.4-64.8) %.

Keywords: Rice Husk, Rice Straw, Fibrecrete blocks, lightweight blocks.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
BS	British Standard
CH	Calcium Hydroxide (Portlandite)
C-S-H	Calcium Silicate Hydrates
FRC	Fibre Reinforced Cement Composites
GDP	Gross Domestic Product
LEDCs	Less Economically Developed Countries.
MLHUD	Ministry of Lands, Housing and Urban Development
NDP	National Development Plan
NEMA	National Environmental Management Authority
OPC	Ordinary Portland Cement
QTM	Quick Thermal Conductivity Meter
RH	Rice Husk
RS	Rice Straw
SDG	Sustainable Development Goals
SEM	Scanning Electron Microscope
UBOS	Uganda Bureau of Statistics
UN	United Nations
UTM	Universal Testing Machine
w/mk	Watts per meter kelvin

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Uganda is a Developing Countries with a moderate tropical climate and a high rate of low-income housing. In fiscal year 2020/2021, agriculture employed about 70% of Uganda's working population and accounted for about 23.7% of GDP, and 31% of export earnings (UBOS, 2021).

Uganda's progress towards achieving inclusive sustainable growth is curtailed by poor and limited infrastructure. About 38% of Uganda's population live below the international poverty line with around 60% of the urban population living in hygiene conditions especially slums areas (Malik, 2014).

One of the indicators for assessing the living conditions of a population is the housing, it has profound impact on health and welfare of an individual. The Universal Declaration of Human Rights of 1948 recognizes the right to housing as an important component of human rights. Other international declarations and charters such as the International Covenant on Economic, Social and Cultural Rights of 1966, Agenda 21 of 1992, the Istanbul Declaration and Habitat Agenda of 1996 recognises the right to housing. Similarly, the African Charter on Human and People's Rights (1986), the East African Community Treaty and Goal 11 of Sustainable Development Goals (SDG) have further reaffirmed the importance of the right to decent housing. The Government of Uganda too recognizes the strategic social and economic importance of housing in the National economy and, particularly, to the Socio Economic Transformation of the Country as highlighted in Vision 2040 (MLHUD, 2016).

About six (6) million Ugandan families live in 4.5 million residential units with means an average occupancy density of 1.3 families per dwelling. The conditions in these residential slum areas more critical with majority of whom living in one room rented houses (Hashemi et al., 2015).

Uganda National Household Survey 2009/2010 indicate that, 33% of Ugandan families use two rooms while 44% use only one room for sleeping (UBOS, 2010). The situation is more critical in Kampala where around 70% of households use only one room for sleeping. The number of persons sleeping per room are proxies to indicate the extent of crowding in households and this information is useful in planning for future housing needs.

Overcrowding is a key problem in Uganda, the mean number of inhabitants in many houses, mostly in built-up areas exceeds two persons per room of $10.22m^2$, the one recommended by the International Standards. This compromises the health, safety and welfare of the inhabitants and increases the risk of contracting infectious diseases such as Covid -19, tuberculosis, measles and meningitis.

Social transformation entails access to decent shelter by the population in both rural and urban settings. Housing is essential for the well-being of humankind and the conditions of the house are important in improving the sanitation status of a household. In addition, the condition of a structure could be a proxy indicator of the welfare status of a household.

Uganda has a housing shortage of 2.1 million units, this is growing at rate of 200,000 units a year; in 2030 the shortage is expected to reach 3 million units. This is as a result of the rapid urbanisation rate and high population growth rates of 3.2 percent per annum. This rate continue to distress the country's housing sectors. Even though more housing units are needed, construction costs are still high as reflected by the rising construction sector indices. The demand for low cost sustainable building materials is growing as social, economic and environmental issues evolve in today's society. The urgent need to develop suitable and affordable housing is born by the fact that over one billion people in the world most of whom live in developing countries are either homeless or live in very poor housing (Mostafa & Nasim, 2015).

Uganda's construction sector needs to be industrialised so as to improve on the supply of housing to its citizens. Industrialization comprises development and standardization of local materials. According to Alinaitwe et al., (2006), "Industrialisation assumes that most materials are standardised and the materials and their components can be manufactured in several places and these components can fit in the final product without discrimination based on origin".

In Uganda, the commonest materials used for constructing walls are mud and timber poles, bricks and blocks. Good quality walls provide protection for household members from severe weather conditions and from exposure to hazardous features. About 67% of the households in Uganda live in residences with brick walls whereas 28% have walls made of mud reinforced with timber poles UBOS, (2017). Brick masonry with embodied Energy at 580.2 GJ consumes highest energy in comparison to all other common masonry options (Mishra & Usmani, 2013).

The use of burnt bricks for walling has detrimentally affected the country surroundings leading to issues like deforestation, desertification, air pollution, extreme agricultural soil extractions, food and fuel crisis, and health concerns (Perez-Pena, 2009). The current circumstances of using burnt bricks can cause social and environmental tragedies if no positive remedies are put in place to improve the disorders.

National Development Plan (2016), reported that, the forest cover has gone down from 4.9 million hectares in 1990 to 3.6 million hectares in 2015, representing a 27% drop.

The advance of native building materials in a viable way has economic, environmental and health benefits. It lessens house production costs, a very vital aspect for the successful access to decent housing by low-income earners. This also protects the eco-system, and contributes to progress of the living environment of the communities.

The demand for quality building material in Uganda is on the rise due to the current boom in the construction industry as reported in the National Population and Housing Census of 2016 by UBOS, increased population led to increased demand for housing units.

Indigenous construction materials have the prospect of supporting sustainable development of decent, low-cost housing that require less input regarding labour, technical knowledge and skills thus facilitating efficient energy use and conservation systems. The use of indigenous constructions materials has remained hidden and unexploited by the recognised construction sector for long because little has been done to develop local building materials. It is imperative to exploit this potential in a sustainable manner to ensuring that, the limited resources are used reasonably.

Local building materials are abundantly available, their efficient utilisation in developing decent housing is still a challenge as they are largely unprocessed, underdeveloped and un-standardised, limiting their potential. These factors lead to inefficient and unfavourable exploitation of the materials manifest themselves in low acceptability, unstable cost of local building materials in Uganda, and puts their sustainability in question.

The increase in popularity of using environmentally friendly, low cost and lightweight construction materials in building industry has brought about the need to investigate the effects of rice husk and rice straw on the properties of lightweight fibrecrete blocks to benefit the environment and maintain the material requirements.

1.2 Problem Statement

Sustainability is one of the focuses of the recent international housing development strategies (Madurwar, 2013). At present, over 90% of framed structures in Uganda are built from reinforced concrete with bricks or block infill walls (Kyakula & Tayebwa, 2011).

However, most of the materials used for the construction of these infill walls are heavy for instance brick infill walls have unit weight of about 20kN/m^3 Sujit et al., 2020, thus influencing the type and size of building foundation and other structural members by their dead loads hence an increased cost of construction (Gunduz, 2007).

In the recent years, reducing the weight of concrete masonry blocks have been proposed by either modifying the block material or the block size or shape. Lightweight building materials are locally and abundantly available, their effective utilisation in developing decent housing is still a challenge as they are mainly unprocessed, underdeveloped and un-standardised, limiting their potential. These factors have led to inefficient and unfavourable exploitation of these materials thus manifesting into low acceptability, unstable costs thus their sustainability is under investigation.

Uganda produces 350,000 metric tons of rice annually Nampanya et al., (2021). Each kilogram of milled white rice produces roughly 0.20 kilograms of rice husk Setya, (2019) and 0.74-0.79 kilograms of rice straw Nguyen et al., (2016a), thus an estimated 70,000 metric tonnes of rice husk and 259,000-276,500 metric tonnes of rice straw is generated in the country per year. Currently, only about 20% of rice straw is used for practical purposes, such as production of biofuels, paper, fertilizers and animal feed, and after harvest most is either burned in situ, incorporated in the soil, or used as mulch (Hanafi et al., 2012).

There is need to investigate reduction of the weight of blocks by use of rice husks and rice straw; this may subsequently improve their benefits such as efficient masonry construction activities, lighter building materials, cost saving enhancement of environmentally friendly design.

1.3 Objectives of the Study

1.3.1 Main Objective

To investigate the effects of rice husks and rice straws on the properties of 'lightweight fibrecrete blocks'.

1.3.2 Specific Objectives.

The specific objectives of the study were:

- To establish the mix proportions of constituent materials suitable for production of 'lightweight fibrecrete blocks' using rice husks and rice straws.
- To evaluate the density, water absorption, thermal conductivity, fire resistance and compressive strength of 'lightweight fibrecrete blocks' produced using rice husks and rice straws.
- To Establish how the Microstructure of 'lightweight fibrecrete blocks' produced using rice husks and rice straws influences its properties.

1.4 Research Question

- What mix proposition is suitable for producing 'lightweight fibrecrete blocks' using rice husks and rice straws?
- What is the density, water absorption, thermal conductivity, fire resistance and compressive strength of 'lightweight fibrecrete blocks' produced using rice husk, rice straws?

- How does the Microstructure of 'lightweight fibrecrete blocks' produced using rice husk, rice straws influence its properties?

1.5 Justification

Rice is one of the important staple foods, particularly in the developing countries. In Uganda, it is largely grown in Districts of Nwoya, Apac, Pallisa, Lira, Bugiri, Jinja and Iganga, Masindi, Luwero. Uganda produces 350,000 metric tons of rice annually (Nampanya et al., 2021) thus generating rice husk and rice straw as wastes. Currently, only about 20% of rice straw is used for practical purposes, such as production of biofuels, paper, fertilizers and animal feed, and after harvest most is either burned in situ, incorporated in the soil, or used as mulch for the following crop; these are either thrown away or burned in open air (Hanafi et al., 2012). Open air burning of rice straws and husks releases noxious greenhouse gases to the air and poses serious threats to human health. Therefore, it is a dual benefit option for farmers to use rice straw and husks as a raw material for construction.

About 2.1 million Ugandan lack housing facilities, this shortage is growing at rate of 200,000 units yearly and expected to reach 3 million units in 2030. This is as a result of the high rate of urbanisation and high population growth rates of 3.2 percent per annum. This high population growth rate continues to extremely upset the Country's housing sectors. The average national household size in 2019/2020 was 4.6 persons with an average number of occupants per room of 2.9 persons (UBOS, 2020). Overcrowding threatens the health, safety and welfare of the inhabitants of the housing units. For instance overcrowding increases the danger of contracting transmittable diseases such as Covid-19, tuberculosis, measles, meningitis, and other contagious diseases.

1.6 Significance of the Study

This research will contribute to knowledge and deliver significant aids to the researchers, consultants, governments of developing countries like Uganda and other users of ‘’fibrecrete blocks’’. The significances of this study will be structural, economic, environmental and social benefits.

The selection of sustainable construction materials and design to in building low-cost housing can be supportive in addressing not only economic and social issues but also environmental matters such as deforestation. According to (Al-Sakkaf, 2009) there is need to build houses that are long-lasting and at affordable cost. Producing low-cost housing units will enable people in the low-income bracket to secure decent housing units, reduce the environmental effect of construction activities and reduce the housing deficits especially in the Less Economically Developed Countries.

Structural significance of the reduced weight of blocks is that: the reduction of quantities of materials used like steel, and reduction in the foundation size and other structural members. This reduction in sizing and material for housing construction provides low-cost and affordable housing, since affordable housing is one of the major concerns of every government and its citizens.

The Construction Industry is a major source of Carbon dioxide emission, and therefore the use of agricultural waste fibres for construction can reduce the impact of the industry on the environment. This is because the process involved in manufacturing fibrecrete blocks from agricultural waste has little effect on the environment as compare to burnt clays bricks, which involve burning and cutting down of trees. In addition, instead of burning agricultural waste which emits high carbon that pollutes the Environment, the wastes will be used to produce fibrecrete blocks. This study therefore offers many environmental benefits, comprising reduction of Carbon dioxide release and environmental pollution.

1.7 Scope of the Study.

1.7.1 Content scope

This research was limited to the use rice husks and straws for production of 'lightweight fibrecrete blocks' of dimensions 400 x150 x 200mm, the most used sizes of blocks in Uganda's construction industry. The properties of the 'lightweight fibrecrete blocks' studied include density, water absorption, thermal conductivity, fire resistance, compressive strength and micro structure of the blocks.

1.7.2 Time scope

The study was conducted between August 2019 - October 2022.

1.7.3 Geographical scope

The rice straws and husks were collected at Luwero District in central Uganda and Masindi District in western Uganda respectively while the tests were conducted from Kyambogo University, Makerere University and Busitema University and GFS laboratories in Kira town council, Wakiso District.

1.8 Conceptual Framework

This network shows how the objectives of the study were achieved by relating the variables that were investigated in the study.

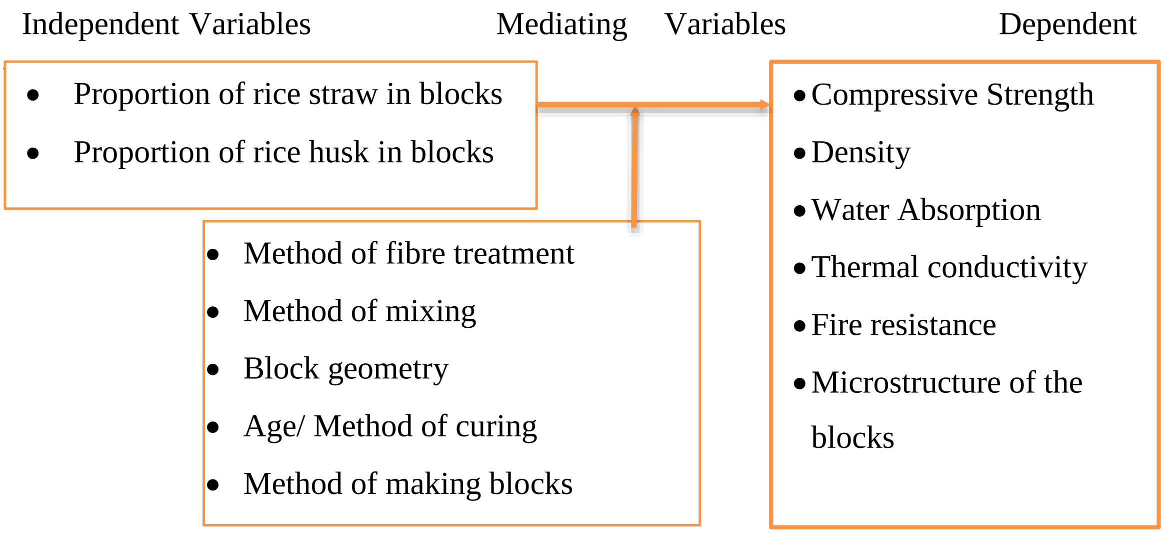

Figure 1-1: Conceptual framework

1.9 Chapter summary

This chapter provided background to the study, statement of the problem, research objectives and questions, scope of the study, justification and significance of the study. It also laid down a conceptual framework to be followed in the study. The subsequent chapter considered literature to the variables under research.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction.

This chapter presents the general composition and behaviour of natural fibres in cementitious composite like fibrecrete. It also covers a brief study on the life span of natural fibres in cementitious composite and the remedies to overcome the durability issues in cementitious composite by fibre modification.

The chapter also captured the properties of fresh cementitious composite and the hardened composites. It further covered a review of different test on concrete blocks and concludes with a review of published studies.

2.2 Overview of sustainable constructions.

Sustainable development is the idea that human societies must live and meet their needs without compromising the ability of future generations to meet their own needs. According to Brundtland, (1987), 'sustainable development is a way of organizing society so that it can exist in the long term taking into account both the imperatives present and those of the future, such as the preservation of the environment and natural resources or social and economic equity'.

Sustainable construction is viewed as construction and management of the built environment. Entirely aspects of sustainable human settlements and urban sustainability recognize that humankind is sealed into a highly dynamic relationship with the natural world and that the two are interdependent.

In addressing the complex difficulties of construction and environment aimed at achieving sustainable construction, fundamental efforts need to be put in place practice to restore the balance between the natural and built environments. Sustainable construction implies not only new environmentally leaning construction designs, but also new environmentally friendly operation and maintenance measures. Not only must construction materials and components be made in a sustainable way, but their use must also answer to new requirements deriving from holistic environmental fundamentals.

The main advantage of lightweight blocks over dense aggregate blocks comes from a combination of higher insulating properties and a lighter unit weight. The lighter block also enables time and material cost savings through easier handling and larger units. Lightweight blocks reduce dead weight of walls in framed structures by more than 50% as compared to brickwork resulting in substantial savings. Due to the bigger and uniform shape of blocks, there is a saving in bed mortar and plaster thickness. Considering that, a substantial amount of steel is necessary only to carry the weight of the structure; steel requirement might reduce by hundreds of ton in high-rise structures.

2.3 Natural Fibres

Natural fibres are categorised basing on the sources, they are grouped into plant, animal and mineral fibres. The physical, thermal and chemical properties of natural fibres are also very diverse depending on the group (Akil et al., 2011; Mindess, 2007).

Plant fibres are commonly categorised depending on plant part from which the fibre is extracted. They are grouped into seed fibres examples like cotton, kapok, bast or stem fibres examples like hemp, flax, jute and kenaf; stalk fibres examples such as bamboo; fruit fibres such as coir (coconut); leaf fibres such as sisal and banana (Akil et al., 2011; Pacheco-Torgal & Jalali, 2011).

Regarding plant fibres, several methods that can be used to separate the fibres from the other plant parts include retting, scrapping and pulping. Plant fibres are available all over the world; they can exhibit high Young’s modulus and tensile strength (Pacheco-Torgal & Jalali, 2011).

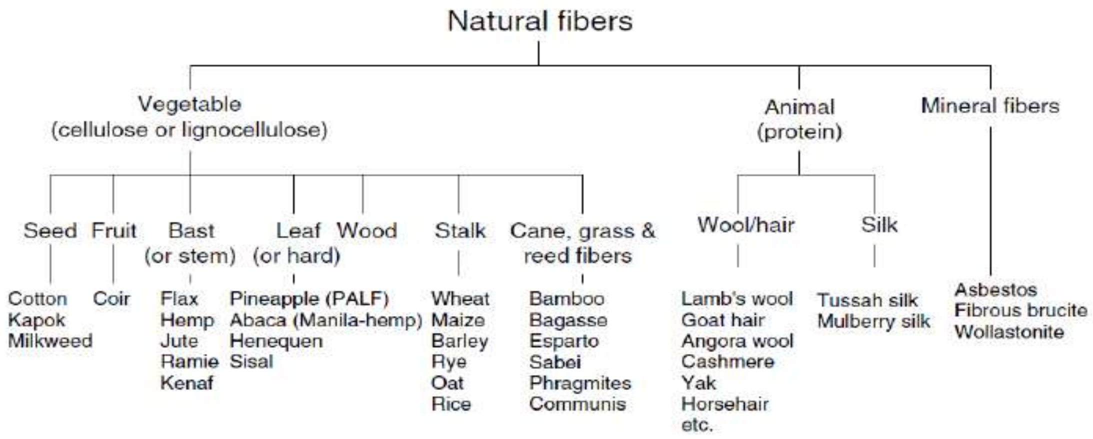

Figure 2-1: Classification of natural fibres (Akil et al., 2011)

2.3.1 Advantage of Natural Fibres.

The usage of natural fibres to develop composite construction materials provides several advantages such as lightness, better rheological behaviour, a good flexural and compressive strength, modulus of crack, renewability and low environmental impact related to their production (Ajouguim et al., 2020).

Natural fibre based composites are environmentally friendly; applications of natural fibre reinforced composites as construction material in creating built environment holds the enormous potential and are critical for achieving sustainability (Susheel et al., 2009).

The processing of natural fibre composites, there is no abrasion of the processing machines (Sreekala et al., 2000). The biodegradability, renewable character, low processing energy in the case of chopped natural fibres makes natural fibres good for natural composites (Santos et al., 2015).

Natural fibres are lightweight (Ali et al., 2016). The density of natural fibres (1.2-1.6 g/cm^3) is lower than glass fibre (2.4 g/cm^3), The vegetable fibres have low densities of approximately half the density of glass fibre (Sreekala et al., 2000), which leads to the making of the lightweight composites and therefore good for producing lightweight materials (Girijappa et al., 2019). Therefore, natural fibres such as hemp, jute, sisal, banana, coir, and kenaf are extensively used in the production of the lightweight composites (Amato et al., 2011).

Economically natural fibres are inexpensive in relation to other conventional building materials and their convenience at modest cost and in diverse morphologies and dimensions, less cost in processing (Wang et al., 2007; Santos et al., 2015).

2.3.2 Disadvantages of Natural Fibres.

The disadvantage of natural fibre composites includes poor fibre matrix interfacial bonding, poor wettability, and water, moisture absorption. The hydrophilic nature of the natural fibres caused poor interfacial interaction between the matrix and the fibre (Girijappa et al., 2019; Susheel et al., 2009). To improve the adhesion between fibres and matrix pre-treatment using hydroxyl groups activate the fibre can be done or new materials added to effectively interlock with the matrix (Susheel et al., 2009).

2.3.3 Effect of Moisture on Natural Fibres

Although natural fibres are worth for cement matrix reinforcement, they have their setbacks when used as a composite. One of the snags is high water uptake of the fibres. This difficult situation has the trend of reducing the interfacial bond strength of the fibres within the cement matrix (Girijappa, et al., 2019; Susheel, et al., 2009).

2.3.4 Chemical Compositions and Structure of Natural Fibres

The structure and chemical composition of natural fibres are rather complex. Natural fibres are composed of Cellulose, Hemicelluloses, Lignin, Pectin, Waxes, and other water-soluble compounds (Pacheco-Torgal & Jalali, 2011; Girijappa et al., 2019).

The presence of Cellulose that is hydrophilic in nature affects the interfacial bonding between the cement matrix and the fibres because the matrix is hydrophobic (Girijappa et al., 2019). Basing on the chemical analysis of natural plant fibres, cellulose fibrils are the main component (Akil et al., 2011; Onuaguluchi & Banthia, 2016).

Hemicellulose consist of polysaccharides that consist of 5-6 carbon ring of sugar. Hemicelluloses are simply hydrolysed in acids and liquefied by alkali (Akil et al., 2011).

Lignin are one of vital parts in the development of cell walls for the plant fibres and they grasp the fibre structure together whereas Pectin is the key component of the middle lamella and plays main role to grasp cell walls (Sedan et al., 2008). Pectin are amorphous material that are readily dissolved by alkalis such as NaOH (Le troedec et al., 2011b).

Waxes and fatty substances are smaller components in the structure of plant fibre and normally occur near the surface of fibre, they mainly contain long chain alcohols and ester of carboxylic acids in their structure. Waxes and fatty substances are insoluble in water but can readily be removed from the surface of fibres by alkaline and organic solutions (Akil et al., 2011).

Table 2-1: Chemical Compositions of rice straw and rice husk (Ugheoke & Mamat, 2012)

Constituent	**Rice straw**	**Rice husk**
Cellulose	43%	35%
Hemi cellulose	25%	25%
Lignin	12%	20%
Crude protein (Nx6.25)	3-4%	3%
Ash	16-17% (silica 83%)	17% (silica 83%)

Grouping	Fibre	Cellulose	Hemicellulose	Lignin	Extractives	Ash
Bast	Jute	33.4	22.7	28.0	–	–
	Hibiscus	28.0	25.0	22.7	–	–
	Banana trunk	31.48	14.98	15.07	4.46	8.65
	Banana	60–65	6–8	5–10	–	4.7
Stalk	Sorghum	27.0	25.0	11.0	–	–
	Bagasse	32–48	19–24	23–32		1.5–5
	Bagasse	41.7	28	21.8	4	3.5
Straw	Wheat	33–38	26–32	17–19	–	6.8
	Rice	28–36	23–28	12–14	–	14–20
	Barley	31–45	27–38	14–19	–	2–7
Leaf	Sisal	38.2	26.0	26	–	–
	Sisal	73.11	13.33	11.0	1.33	0.33
	Banana	25.65	17.04	24.84	9.84	7.02
	Pineapple	70–82	18.0	5–12	–	0.7–0.9
	Corn stover	38–40	28.0	7–21	–	3.6–7
Seed	Coir	36–43	0.15–0.25	41–45	–	2.7–10.2
	Coir	33.2	31.1	20.5	–	–
	Coir	21.46	12.36	46.48	8.77	1.05
	Coconut tissue	31.05	19.22	29.7	1.74	8.39
Wood	Eucalyptus	41.57	32.56	25.4	8.2	0.22

Figure 2-2: Chemical Compositions natural fibres (Onuaguluchi & Banthia, 2016)

2.3.5 Durability of natural fibre reinforced cement composites

Durability of natural fibre reinforced cement composites is well-defined as the capacity to battle the processes of deterioration due to either external damage such as chloride attack or internal damage such as compatibility between fibres and cement matrix (Santos et al., 2015; Wei & Meyer, 2015). The low long-term resilience of natural fibres in cement composites has been the main issue that limited their applications in cementitious composites (Santos et al., 2015; Wei & Meyer, 2015).

The decrease of fibre durability is triggered mostly by the alkaline environment of the cement matrix. Continuous degradation may take place due to destruction of the macromolecular chains during the partial alkaline hydrolysis of the cellulose. This causes rupture and consequential reduction of the degree of polymerization of the cellulose chains. This degradation mechanism happens by the easy movement of the pore water to the surface of the fibres (Santos et al., 2015).

The degradation of natural fibres immersed in Portland cement also happens due to the high alkaline environment that dissolves the lignin and hemicellulose phases, thus weakening the fibre structure (Gram, 1983).

Severe degradation of weather-exposed composites can be attributed to interfacial damages owing to continuous volume changes of the porous and hydrophilic cellulose fibres inside the cement matrix (Santos et al., 2015).

Mohr et al., (2006) reported that lignin and wood extractives protect the fibre from mineralization phenomena. Thus, pulp bleaching makes the cellulose chain more susceptible to degradation, which could lead to important consequences for the durability of the fibres in the fibre-cement composite.

To improve the durability of fibre reinforced cement composites, there are various approaches such as fibre treatment, fibre surface modification and modification of the cement matrix (Toledo et al., 2003; Pacheco-Torgal & Jalali, 2011).

2.3.6 Natural Fibre Surface Modification

Different scholars have considered the result of pre-treatment of natural fibres using varied procedures (Bilba & Arsene, 2008; Ajouguim et al., 2019; Kabir et al., 2011; Mostafa, & Uddin, 2015) to modify the fibre surfaces.

Pre-treatment of fibre can be categorised into three main techniques: mechanical treatment by pulping methods like Kraft process; thermal treatment by the removal of water from cellulosic fibres over many cycles of drying and re-wetting and chemical treatment by some chemical agents and coating (Pacheco-Torgal & Jalali, 2011; Santos et al., 2015).

The commonest plant fibres treatment method is by using chemicals like the alkalis, water repellents, saline, peroxides, and permanganates. This is aimed at decreasing their moisture absorption and compatibility with various matrix (Parveen et al., 2017).

The chemical pre-treatment of fibres by chemical agents or coating is gaining popularity although the alkaline environment of cement matrix causes reduction of fibre durability (Toledo Filho et al., 2000; Santos et al., 2015).

According to Bachir & Abdelhamid, (2016), chemical treatments such as alkali treatment are meant to increase the fibre/matrix adhesion by improving surface roughness of the natural fibres by cleaning the fibre surface from contaminations and disrupting the water absorption process via the layer of OH groups in fibre.

In order to improve fibre- cement matrix adhesion, various fibre surface treatments have been carried; these results in changing surface tension and polarity through modification of fibre surface. Several classes of compounds are known to promote adhesion, by chemically coupling the adhesive to the material (Wang et al., 2007). The chemical composition of coupling agents allows them to react with the fibre surface and forms a bridge of chemical bonds between the fibre and cement matrix to increase the fibre/cement matrix adhesion (Wang et al., 2007).

The alkaline character of the cement matrix leads to reductions in the natural fibre durability causing deterioration of the fibre microstructure that results to the decrease of the composite performance (Sawsen et al., 2015).

The different treatment methods offer good fibre/cement matrix link as well as a better hardening performance. Alkaline treatment is most used method due to its cost effectiveness. It eliminates weak boundary layers from the surface natural fibres, which protects fibres against the cement alkali medium (Hashim et al., 2017).

Alkali treatment leads to the creation of new functional groups on fibres surface (Ajouguim et al., 2019). This provides a thin layer on fibres surface that resist the effect of alkali environment. However, treating fibres with chemical solution reduces the effect of alkali attack and overcomes the weak bond between the fibres and cement matrix by formation of a rough fibre surface (Machaka et al., 2014).

2.3.6.1 Alkaline treatment of natural fibres

Alkaline treatment of fibre using chemicals like sodium hydroxide ($NaOH$) is one of the most used methods for fibre surface modification in reinforced cement composites (Machaka et al., 2014). Un-treated fibres has some impurities on its surface, Le Troedec et al., (2008) reported that the impurities on natural fibres are mostly waxes or fatty substances. Sodium hydroxide ($NaOH$) treatment is well-known to bleach and clean the surface of plant fibres and eliminate amorphous materials such as hemicelluloses and pectin from their surface and thus making the surfaces to develop extra homogeneity.

The alkaline treatment are effective in removing the superficial lignin layer from the fibre, hot water and sodium hydroxide cause fibre fibrillation and sodium hydroxide is effective in promoting both decrease in fibre diameter and increase in fibre surface area. The lignin is insoluble in most solvents but it is soluble in hot bases (Kumar et al., 2009).

Alkaline treatment enhance fibre stiffness and expedite re-arrangement of fibrils along the direction of the tension force after eliminating binding materials (Zin et al., 2018). Alkali treatment leads to increased surface roughness and better mechanical bonding due to exposure of cellulose on the fibre surface. This increases the number of possible reaction sites and allows improved fibre wetting (Mostafa, & Uddin, (2015), Sedan et al., (2008).

Fibre–OH + NaOH → Fibre–O–Na^+ + H_2O……..…………………….. Eqn (1)

According to Akil et al., (2011), alkaline treatment has two effects on the fibre: it increases surface roughness, resulting in better mechanical interlocking; and it increases the amount of cellulose exposed on the fibre surface, thus increasing the number of possible reaction sites. Consequently, alkaline treatment has a lasting effect on the mechanical behaviour of natural fibres, especially on their strength and stiffness.

Chemical treatment (NaOH, $Ca(OH)_2$ and $CaCl_2$) on surface structure of hemp Le Troedec et al., (2008. He established that NaOH treatment was better than other treatment and NaOH bleached and cleaned the surface of hemp fibres and removed amorphous materials such as hemicellulose, pectin and impurities (fatty materials and waxes) from their surfaces.

A solution of 10-30% sodium hydroxide produced the best effects on natural fibre properties Sreekala et al., (2000).

Yan et al., (2016) studied, untreated and alkali-treated (5% NaOH solution at 20^0C for 30 min) coir fibres used as reinforcement; they observed that core fibre treated with 5% NaOH solution causes a clearer and rougher surface of the coir fibre, compared with the untreated fibre surface.

Bisanda, (2000) found that the treatment of sisal fibre with 0.5% NaOH solution improved the compressive strength and reduced the water absorption of the sisal/epoxy composites. The dewaxed fibres were then soaked in a 0.5M solution of sodium hydroxide, i.e. 20 g of solid alkali in 1 litre of distilled water for 24 hrs and 72 hrs then rinsed in distilled water and dried.

Yan, (2012) used 5% NaOH solution to modify flax fabrics; he found that the oil and wax impurities on the flax fibre surfaces were removed after the treatment. The surface of the treated flax fibres were rougher and cleaner which facilitated both chemical and mechanical bonding between the fibre and the polymer. As a result, the mechanical properties such as tensile and flexural properties of the flax/epoxy composites were enhanced.

Alsaeed et al., (2013) investigated the impacts of alkali treatment on interfacial adhesion of date palm fibre with epoxy matrix by means of single fibre pull out technique. The study was conducted by using sodium hydroxide treatment concentrations of (0–9%), fibre length and fibre diameter on the adhesion between fibres and matrix. The finding revealed that 6% concentration of NaOH leads to a high interfacial adhesion and strength between date palm fibre and epoxy matrix.

2.3.6.2 Hot water treatment of natural fibres

Straws treated with hot water seems to be very good in cement/fibre matrix bond, increased mechanical strength, the hot water leads to a good adhesion between the fibres and the cement matrix (Sellami et al., 2013). The hot water seems to be the best treatment that easily dissolves the sugar contained in the plant fibres that increases the compatibility between the two materials.

In a study conducted by Bederina et al., (2016) using hot water, gasoline, varnish, and waste oil to treat barley straw to increase the performance of lightweight composite concrete. The results indicate that hot water treatment method significantly improve the tensile strength of barley straw. The straw treated with hot water, gasoline, varnish, and waste oil has positive effects on improving the flexural strength, less shrinkage, and density of concrete.

2.3.7 Challenges with plant fibre-reinforced cementitious composites.

The drawbacks of plant fibres is the variability of the physical and mechanical properties of the fibres that originates from variances in their chemical structure and composition, like cellulose content, degree of polymerization, orientation of molecular chains, crystallinity (Thomason et al., 2012; Onuaguluchi & Banthia, 2016). These parameters are extremely dependent on the growth conditions of the plant and fibre extraction methods (Pacheco-Torgal & Jalali, 2011). Therefore, fibres extracted from different plants parts or grown in weather conditions present huge variability in their length, cross-sectional area, and mechanical properties (Parveen et al., 2017). High variability of plant fibre properties is a problem when developing products based on plant fibres.

The high moisture absorption of plant fibres leads to problems when used in cementitious materials, plant fibres swell due to intake of moisture and shrink due to removal of water during dry atmosphere and high temperatures. When plant fibres are used to reinforce cementitious matrix, the frequent swelling, shrinking occurrences leads to formation of cracks. These cracks reduce the mechanical performance and durability of cementitious composites.

The high absorption of alkaline solution present within the cement mixture leads to degradation of plant fibres with time and this subsequently causes deterioration of properties of plant fibres as well as plant fibre reinforced cementitious composites.

In conditions where the plant fibres are not well saturated during mixing with cementitious materials, they absorb considerable volume of water and lessen the water required for cement hydration. This reduces degree of cement hydration and, consequently, poor mechanical performance of cementitious composites (Onuaguluchi & Banthia, 2016).

Reduced interfacial bond between the plant fibres and different matrices present one of the major problems with plant fibre composites (Parveen et al., 2017). Poor interface results in inferior load transfer between fibre and cement matrix, resulting in lower mechanical performance. Due to the hydrophilic nature of the fibres, the interface formed between plant fibres and hydrophobic matrices is very weak. On the other hand, the interface of plant fibres with hydrophilic matrices can be better because of interfacial hydrogen bonds; the high moisture absorption of plant fibres, breakage of interfacial hydrogen bonds occurs in the interfacial region, failing the fibre/matrix bonding (Kabir et al., 2011).

The long-standing stability of plant fibres and plant fibre-reinforced cementitious composites is doubtful. The cement matrix presents an alkaline environment, which accelerates the degradation of plant fibres due to dissolution of lignin and hemicellulose in alkaline solution.

During the moulding process of plant fibre cement-based composites products, plant fibres with high water absorption are likely to agglomerate to make plant fibre cement-based composites mixture difficult to mix evenly. This would affect not only the workability of mixture but also the performance of hardened plant fibre cement-based composites. For plant fibre, cement based composites mixture reaching the same consistency, the amount of water for mixing increases. The excessive water evaporates or stays in concrete, forming capillary holes, pores or bubbles, which reduces the effective section of hardened plant fibre cement-based composites and tends to produce stress concentration around these pores.

Plant fibres with high water absorption are easy to inhale alkali solution in the alkaline environment of cement hydration and cause corrosion damage, which leads to the decrease or even loss of the original properties of plant fibres. In addition, during the process of absorbed water release, the sugar components in plant fibre extracts block hydration and hardening of cement.

Plant fibres with high water absorption also have a problem of dry shrinkage and wet expansion leading to volume change of plant fibres, affecting the bond strength between fibres and cement-based materials and reducing the reinforcing, toughening, and anti-cracking of fibres.

Natural fibres are strongly hydrophilic in nature and their moisture absorption leads to a significant deterioration of their mechanical properties. Furthermore, most polymers are hydrophobic and owing to this deviating behaviour, the interfacial bond in the natural fibre composites is rather reduced. Alteration of the characteristics of the cell wall, either chemical or morphological, has an effect on the mechanical properties of the fibres. By limiting the substitution reaction to the fibre surface, the good mechanical properties are reserved and a degree of biodegradability is maintained (Wang et al., 2007).

2.4 Properties of fresh cement composites.

2.4.1 Setting Time

Plant fibres have negative effect on the hydration behaviour of Portland cement Parveen et al., (2017), Savastano et al., (2000), Bilba et al., (2003) mentioned that OPC setting time delays due to acid compounds released from natural fibres reduce the setting time of the cement matrix.

The reasons attributed to this effect include:

The fibre sugar components, hemicellulose and lignin can contribute to avoidance of cement hydration. The production of soluble sugars leads to hydrolysis of lignin and partial solubilisation of hemicellulose (Parveen et al., 2017; Onuaguluchi & Banthia, 2016). The Calcium compounds produced within the cementitious matrix due to dissolution of sugars delays the hydration process by letting down cement hydration temperature and delaying the formation of hydration products (Onuaguluchi & Banthia, 2016).

Pectin existing in plant fibres act as inhibitor for the development of calcium silicate hydrate (CSH) (Parveen et al., 2017, Sedan et al., 2008). According to Sedan et al., (2008) fibre addition can delay setting by 45 min. This is attributed to the fact that pectin (a fibre component) can fix calcium preventing the formation of CSH structures.

Carbohydrates and hemicelluloses present in wood and plant fibres reduce the speed of hydration of cement. The addition of pozzolana reduces the negative effect of plant fibres on cement hydration. Treatment of plant fibres to eliminate lignin, increased curing temperature, addition of chemical accelerators and supplementary materials also speed up hydration of cement (Parveen et al., 2017).

2.4.2 Flow of cement composites (Workability).

Integration of plant fibres within cement mixtures decreases its workability, depending on the fibre volume fraction and aspect ratio (Ardanuy et al., 2015). This reduction in cement composite flow behaviour caused by addition of fibres is attributed to their hydrophilic nature and absorption of water from the cement mixture (Ardanuy, et al., 2015, Onuaguluchi & Banthia, 2016). The key factors, which influence the degree of workability loss in natural fibre reinforced cement mixtures, are fibre aspect ratio and volume fraction in mixtures (Onuaguluchi & Banthia, 2016).

To obtain a cement composite mixtures with satisfactory workability, it is recommended that: the surface be treated or pre-saturated or increase water/cement ratio used, taking into account the water absorption of the plant fibres all these are done to reduce their hydrophilicity (Ardanuy et al., 2015). Fibre pre-treatment can also lessen the water absorbing chemical components of fibres (Onuaguluchi & Banthia, 2016).

2.5 Properties of Hardened cement composites.

2.5.1 Moisture absorption.

Absorption is a process by which a liquids gets into and tends to fill the open pores in a porous solid body such as a component of concrete (ASTM C125, 2021). The absorption is generally more significant in surface layer than the core of concrete due to strong capillary action. The rate at which a dry concrete surface absorbs a liquid can be taken as a predictor of the durability of concrete (Salem & Al-Salami, 2016). Water is the commonest used liquid in concrete hence, water absorption is widely used to show the absorptivity of concrete. Moisture absorption can be determined based on the rise in mass of a concrete specimen as a result of penetration of water into its open pores. The porosity of the concrete controls the microstructure and thus the absorption of concrete, depending on the relative quantities of the pores of various types and sizes. When the porosity drops, the water absorption is also reduced (Salem & Al-Salami, 2016).

Lightweight concretes have higher water absorption values as compared to normal weight concretes. The high water absorption does not necessarily indicate that concretes will have reduced durability or high permeability (American Concrete Institute, 1980).

Previous researchers have failed to disclose any dependable relationship between water absorption of concrete and its durability. The durability of lightweight concrete and normal weight concrete is a function of the cement paste quality, quantity of air entrained in the cement paste, and the quality of the aggregate itself (American Concrete Institute, 1980). Permeability depends primarily on the quality of the cement paste (American Concrete Institute, 1980).

To have a sustainable structure, durability is key. Use of inappropriate materials, poor construction practices, curing and mix designs, results in structures often showing serious premature deterioration.

Natural fibres are hydrophilic in nature; they absorb moisture from the atmosphere. Owing to this moisture absorption by fibres, the hydrogen bond breaks and hydroxyl groups form a new hydrogen bond with water molecules. This causes swelling of the natural fibres within the hydrophobic matrix leading to dimensional instability, matrix cracking and poor mechanical properties (Kabir et al., 2011, Parveen et al., 2017).

Cellulosic fibres being hydrophilic in nature absorb moisture from environment until equilibrium is established; the moisture regain of natural fibres vary between 5% and 12% (Ali et al., 2016). The moisture absorption causes dimensional variations in the fibre as well as composite material, thus affecting the interface and the mechanical properties of composite material (Ali et al., 2016).

The reduction of fibre durability is caused mostly by the alkaline (pH around 12) environment of the cement matrix. Some progressive degradation mechanisms may take place, such as the destruction of the macromolecular chains during the incomplete alkaline hydrolysis of the cellulose, which causes their rupture and the consequent decrease of the degree of polymerization of the cellulose chains. This degradation mechanism occurs by the easy movement of the pore water towards the surface of the fibres. Other mechanism is the gradually filling of the inner cores of the vegetable fibres with the cement hydration products, leading to the embrittlement of the fibres, and reducing their mechanical performance (Santos et al., 2015). Furthermore, the strength of the composite decreases in the long-term. The severity of degradation of weather-exposed composites can also be attributed to interfacial damages owing to continuous volume changes of the porous and hydrophilic cellulose fibres inside the cement matrix (Santos et al., 2015).

During composite fabrication, the moisture may lead to poor fibre-matrix interface thus affecting effective transfer of load due to poor interface and the composite material will deteriorate (Ali et al., 2016).

The results of studies by Hou et al., (2016) on heat-moisture coupling transmission of hollow concrete blocks occupied with compressed straw bricks show that, filling compressed straw bricks into hollow concrete block can prevent heat transfer and increase moisture-buffering performance of multilayer walls.

2.5.2 Compressive strength

The effects of unwashed and washed rice straw fibres (RSF) on mechanical properties such as compressive strength of coarse RSF and fine RSF was conducted by Ataie, (2018) using concrete mix of w/c of 0.42 and 0.54. He concluded that concrete specimen containing coarse RSF have lower compressive strength as compared to samples with fine RSF.

Cai et al., (2017) investigated the effects of length and content of straw fibres on compressive strength of cement based composite. It was observed that, by increasing the amount of straw content, mechanical properties like compressive strength of cement mix composite reduce at 7 days and 28 days. The shorter the fibres the better the mechanical properties of cement-based straw fibre composite.

2.6 Fire protection

The general objectives of fire protection are to limit risks with respect to the individual and society, neighbouring property, and where required, environment or directly exposed property, in the case of fire; the construction works must be designed and build in such a way, that in the event of an outbreak of fire (EN 1992-1-2, 2004).

- load bearing resistance of the construction can be assumed for a specified period of time
- generation and spread of fire and smoke within the works are limited
- spread of fire to neighbouring construction works is limited
- occupants can leave the works or can be rescued by other means
- safety of rescue teams is taken into consideration.

The load-carrying capacity in the fire situation can be determined considering the following: thermal exposure and the consequent temperature field in the member, reduction of material strength due to elevated temperatures, effects of restraint forces due to thermal expansion and second order effects (EN 1992-1-2, 2004).

Eurocode 4 recommends that an additional loss of 10% of the value at *Tmax* be applied when the maximum temperature exceeds 300°C. The evolution of the compressive strength is taken as varying linearly from *Tmax* down to 20°C. For high-strength concrete, there is virtually no difference up to 400°C and, for higher temperatures from 600°C up to 1000°C, the residual strength after heating and cooling even has a tendency to be higher than the strength at elevated temperature.

According to Yi & Jean, (2011) the additional strength loss that occurs during cooling is significantly higher than the 10% of the strength at maximum temperature proposed in Eurocode 4. It can be as high as 20% of the initial compressive strength for temperatures around 500°C. This additional decrease is due to the 10% loss of strength of concrete that develops during cooling to ambient temperature.

If the applied load ratio happens to be in range from 0.52 to 0.58 in the fire situation, structural failure can occur several hours after the fire has completely finished. Such a tragic incident occurred in Switzerland in 2004 when seven members of a fire brigade were killed by the collapse of the concrete structure in an underground car park in which they were present after having successfully put down the fire (Yi & Jean, 2011).

2.6.1 Fire resistance of natural fibres.

Fire resistance" means the shortest period a building element or component comply with the requirements for stability, integrity and insulation when tested to the fire requirements (EN 1992-1-2, 2004). According to EN 1992-1-2, (2004) for the standard fire exposure, members should comply with criteria of E, I and R i.e. Integrity (criterion E), Insulation (criterion I), and Mechanical resistance (criterion R). Criterion "R" is assumed satisfied where the load bearing function is maintained during the required time of fire exposure (EN 1992-1-2, 2004).

Natural fibre based composites are subject to thermal decomposition due to their exposure to fire or high-intensity heat sources (Lee et al., 2014). Exclusion of ignition of fire is the first priority, but the least is to extend its ignition time. The ignition time widely depends on the heat intensity, the oxygen density, and the airflow in that particular area.

Once fire is ignited, work has to be done to lessen the fire spread rate (Lee et al., 2014, Ferdous et al., 2002).

Natural fibres are composed primarily of cellulose, hemicellulose, and lignin, with the balance being made up of pectin, water soluble compounds, waxes, and inorganic, non-flammable substances, which are generally referred to as ash (Akil et al., 2011; Girijappa et al., 2019; Pacheco-Torgal & Jalali, 2011).

The thermal decay of a natural fibre at all times start at low temperature with hemicelluloses decomposition followed by abrupt drop of mass triggered by the pyrolysis of cellulosic while lignin is the last component to decompose at the highest temperature (Lee et al., 2014).

Cellulosic fabrics have low fire resistance as cited in (Mohamed & Hassabo, 2015). They are composed of carbon, hydrogen (fuels), oxygen (supporter or combustion), and burn effortlessly when subjected to fire. The burning process of cellulosic materials is an oxidation process and it may be accompanied by a flame or glow. Greatest proportion of organic fibres undergo a glowing action after the flame has been extinguished.

Decomposition of cellulose happens at temperatures between 260-350°C and this leads to formation of flammable volatiles gases, non-combustible gases, tars, and char. The high content of cellulose tends to increase the flammability of the fibre. Hemicellulose decomposes between 200 and 260°C but forms more non-combustible gases and less tar than cellulose while the Lignin contributes more to char formation than either cellulose or hemicellulose whereas Lignin starts decomposing from about 160°C and continues to decompose until about 400°C (Mohamed & Hassabo, 2015).

According to Ferdous et al., (2002) hemicellulose is the first to be decomposed at 180-350°C followed by cellulose at 275-350°C, then the lignin decomposes last at 250-

500°C. Their high thermal stability is attributed to their heavily cross-linked structure and high molecular weight.

During thermal decomposition of lignin, relatively weak bonds break at lower temperature while at higher temperatures (>500°C) the cleavage of bonds in the aromatic rings of the lignin takes place radicals, the aromatic rings are reorganised, condensed thus releasing hydrogen (Ferdous et al., 2002).

Fire resistance is determined based on various failure criteria such as thermal and strength failure criteria mentioned (ASTM E119-01., 2001). For instance, an RC member is said to have failed when the temperature in the rebar exceeds 593°C or the member is not able to resist the applied gravity loads (Behnam & Ronagh, 2015). There are also other failure criteria based on deflection and the rate of deflection. These failure criteria are important because, along with excessive deflection of the structural members, the structural integrity cannot be guaranteed. Mostly, the use of deflection and the rate of deflection criteria help in maintaining the safety of the building before any collapse occurs (Behnam & Ronagh, 2015).

Flame-retardant compounds inhibit flammability of fibre and are effectively used for wood, paper, and cellulosic materials to improve on their fire retardation (Ferdous et al., 2002).The flame-retardant treatment of lightweight cellulosic building materials can impart short-term or long-term flame protection depending upon the method of treatment.

Structural failure of a wall in the fire situation occurs when the wall loses its ability to carry a specified load after a certain period. Adequate load bearing resistance desired for safe evacuation of occupants and fire rescue operations and for limiting fire spread as relevant (EN 1996-1-2, 2005).

Concrete does not lose much of its strength up to the temperature of 250°C. The reduction in its strength starts when the temperature goes beyond 250°C. Normally, reinforced concrete structures can resist fire for about one hour at a temperature of 1000°C. Hence, cement concrete is ideally used as a fire-resistant material.

Concrete is not lose it performance at temperatures below 150°C, at temperatures of 150°C upwards, there is some loss of water from the silicate hydrates in concrete. Temperatures above 300°C result in the loss of bound water hence apparent loss of strength of concrete, the main losses are not apparent until above 500°C. Even though flame temperatures are up to double 500°C, the temperature of the internal concrete remains relatively low due to concrete's slow heat absorption. Therefore, only intense fires of long duration may cause any weakening of concrete structures.

Cement type can have influence on strength loss. Cements with fly ash and ground granulated blast furnace slag have lower magnitudes of free calcium hydroxide, which can give reduced hydration loss on heating, and subsequently lower strength loss.

2.7 Thermal Conductivity.

Thermal properties of concrete are vital concerning keeping variant volume change at a minimum in mass concrete. Removing extra heat from the concrete and dealing with like processes regarding heat transfer. The thermal properties include: specific heat, thermal conductivity, and diffusivity. The major aspect impacting the thermal properties of a concrete is the mineralogical structure of the aggregate. Tests for thermal properties are piloted only for providing constants to be used in behaviour studies.

The thermal conductivity of a material is a measure of its ability to conduct heat; it is commonly denoted by k, λ or κ. According to the second law of thermodynamics, heat flow from the hot environment to the cold one in an attempt to equalize the temperature difference.

The thermal conductivity of a material is quantified in terms of Energy transferred Q, which gives the rate, per unit area, at which heat flows in a given direction. In many materials, Energy transferred is observed to be directly proportional to the temperature difference and inversely proportional to the separation.

$$Q = -K \frac{\Delta T}{L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn 2}$$

Where:

Q= Energy transferred, *K*= thermal conductivity, ΔT=Temperature difference within the material, L=thickness of material.

Absolute technique of determining thermal conductivity; Absolute technique is usually used for samples that have a rectangular or cylindrical shape. When conducting this measurement, the testing block is placed between a heat source and a heat sink.

The sample is heated by the heat source with known steady-state power input. The temperature sensors measures the resulting temperature drop ΔT across a given length of the sample afterward a steady-state temperature movement is reached.

The temperature sensors employed can be thermocouples and thermistors. Thermocouples are the most widely used sensors owing to their extensive range of applicability and exactness.

2.7.1 Hot-wire method

The hot-wire method is a transient technique that measures linear temperature increase between heat source and a known embedded point in the test sample.

This method accepts a perfect "one-dimensional radial heat flow" inside the isotropic and homogeneous sample. This is based on the assumption that the linear heat source has infinite length and infinitesimal diameter.

When an electric current of constant intensity passes through the hot wire, thermal conductivity of the test sample can be derived from the resulting temperature change at a recognized distance from the hot wire over a given time.

This method is mostly used to determine the thermal conductivity of materials that have low thermal conductivity such as soils, ice cores and refractory brick, blocks, refractory fibres, plastic refractories and powdered materials etc.

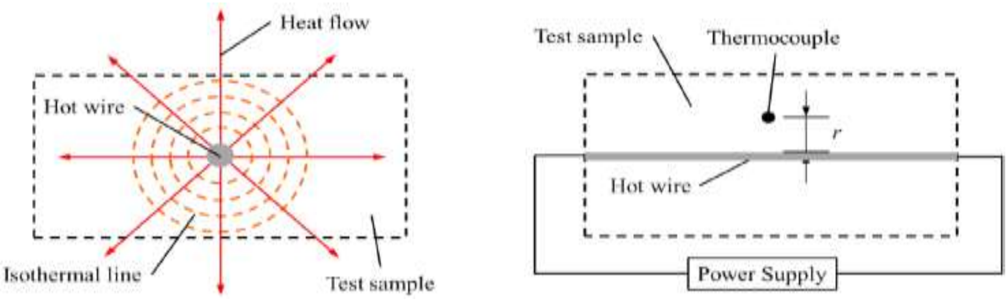

Figure 2-3: The measurement principle of hot-wire method of thermal conductivity

2.8 Durability of building blocks.

The word ‘durability’ may be regarded as a measure of the ability of a material to sustain its distinctive characteristics, and resistance to weathering under conditions of use for the duration of the service lifetime of the structure of which it forms part' (Glanville & Neville, 1997).

Natural fibre reinforced concrete composites have various promising features for sustainable concrete structure applications. But there are many challenges in the promotion of these natural fibre composites. One major difficulty that needs to be addressed for successful commercialization of natural fibre reinforced concrete and natural fibre reinforced polymer composites is their durability.

Natural fibre reinforced composites, the durability is connected to the ability to resist both external and internal injuries Lu (2014). The external harms result from: temperature changes, humidity variations, and sulphate or chloride attack while internal harms are as a result of compatibility between fibres and cement matrix, volumetric changes.

Natural fibres immersed in Portland cement degrades because the high alkaline environment that dissolves the fundamental constituents of the fibres, such as lignin and hemicellulose, and in turn weakening the structure of the natural fibres, as explained by Gram, (1983) who investigated the durability of coir and sisal fibre reinforced concrete. He concluded that the coir and sisal fibres could preserve their tensile strength in carbonated concrete with the value of pH less than 9.

Therefore, for successful application of plant fibres in cementitious matrix, the influence of different degradation parameters should be studied to understand and improve the durability of plant fibres in highly alkaline cementitious composites (Ardanuy, et al., 2015). Different chemical or physical modifications could can be performed on the surface of plant fibres to improve their durability (Ardanuy, et al., 2015).

To increase the durability of natural fibre reinforced concrete, Agopyan, et al., (2005) suggested the use of matrix modification, e.g. using low alkaline concrete and adding pozzolana such as husk ash, blast furnace slag or fly ash to Portland cement. Fibre modification is also beneficial for the durability of natural fibre reinforced concrete using water-repellent agents or fibre impregnation with sodium silicate, sodium sulphite or magnesium sulphate (Ghavami, 1995).

Natural fibres with coatings can be water-resistant and alkaline-free, and in turn improve the durability. Bilba & Arsene, (2008) recommended using saline coating to increase the durability of natural fibre reinforced concrete. For flax fibre reinforced polymer composites, durability also relates to resistance to deterioration resulting from external and internal influences.

To have durable flax fibre reinforced composites, the modification of the poor environmental and dimensional stability of ligno-cellulosic materials, e.g. using duralin treatment of flax fibres to reduce moisture absorption and swelling was recommended (Stamboulis, et al., 2000).

Improved understanding of interfacial properties is also essential to optimise the mechanical properties and durability of bio-composites materials. Le Duigou, et al., (2010) Used different thermal treatments, cooling rate and annealing to increase interfacial bonding of flax fibre/poly (l-lactide) composites.

2.9 Microstructure

Concrete microstructure is defined as the microscopically describing of the concrete components from its macrostructure. The type, amount, size, shape, and distribution of phases existing in a solid constituent of its structure. The gross elements of the structure of a material can easily be observed while the finer elements are usually resolved with the aid of a microscope.

The term macrostructure is mostly used for the gross structure visible to the human eye. The limit of resolution of the unaided human eye is approximately one-fifth of a millimetre (200μm). The term microstructure is used for the microscopically magnified part of a macrostructure. The magnification capability of modern electron microscopes is of the order of 105 times; thus the application of transmission and Scanning Electron Microscopy techniques has made it possible.

Microstructural characteristics such as the interfacial transition zone (ITZ) and cracking patterns are the main features that characterize concrete behaviour (Cristian, 2020). Common technologies such as Scanning Electron Microscope (SEM) are currently employed in petrographic analysis of cementitious materials and concrete microstructure.

In this way, harmful impurities that permeate or diffuse throughout the hardened concrete may initiate its deterioration due to a variation in the ability of the concrete to restrict their transport. Furthermore the cement particles tend to irregularly coagulate and cluster in the mix leading to uneven regions of dense and high porosity hardened paste because of poor dispersion and inhomogeneity during mixing and placing. This holds true even for high density microstructures leading to use of use low water/cement (w/c) ratios. The development of a dense homogeneous microstructure is also affected by the pattern packing of the cement particles and aggregate.

Microstructural development is also controlled by a combination of uniform dispersion of cement particles, mineral admixtures and aggregates along with cement hydration (Roy & Idorn, 1993). Developments occurring at a micro or sub-microscopic level in the concrete matrix influence aspects such as early or retarded setting, drying shrinkage, permeability, frost damage, excessive bleeding, and/or inadequate strength. Understanding the concrete behaviour at these small scale levels is the initial and most important stride toward attaining the means to control its microstructure and influence on performance (Roy & Idorn, 1993).

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter presents the description of the method and the approach that was used in carrying out the study with the intention of finding answers to the research questions derived from the research problem.

3.2 Research Design and Approach

This gives the conceptual structure within which the study was conducted. It constitutes a road map, a plan or blue print for the collection, measurement and analysis of data. This study used factual experimental research design where quantitative data were collected and analysed. The research design is illustrated in Figure 3.1.

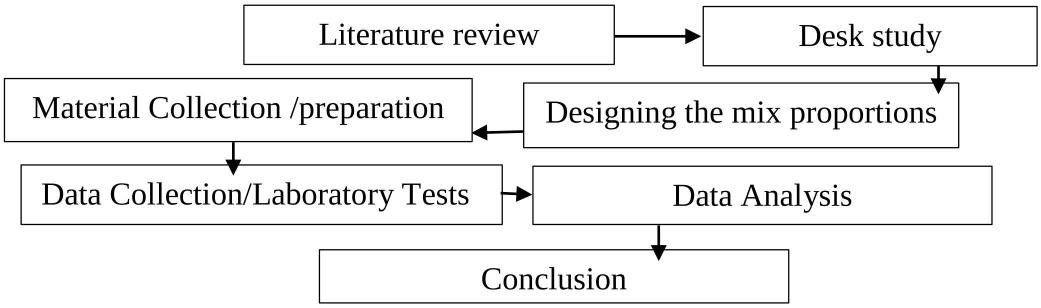

Figure 3-1: Research Design and Approach

3.3Material collection and sample preparation

The materials used in this research include; rice husk, rice straw, fine aggregate (sand), cement and water. Figure 3-2 shows the materials and processes followed during the preparation of the blocks.

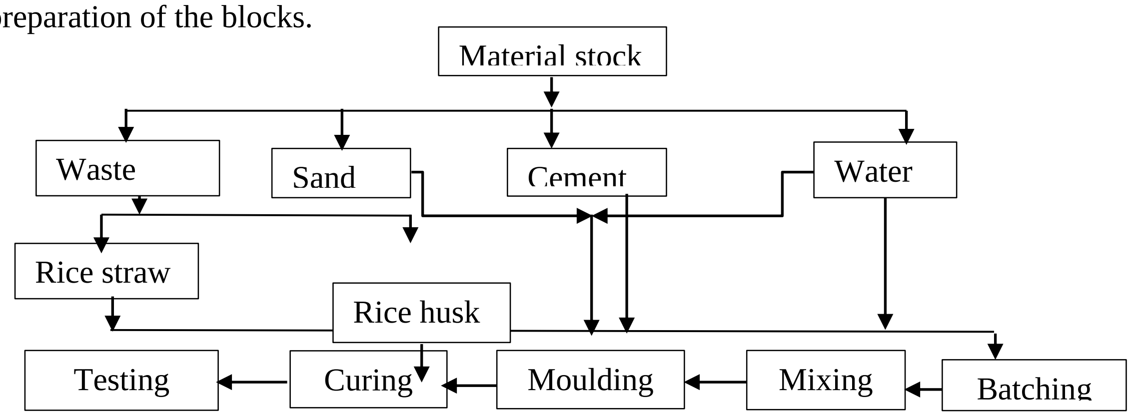

Figure 3-2: Materials and sample preparation

3.3.1 Rice straws

The straws were collected from Kehong Uganda industrial development limited farm located in Luwero District, central Uganda as shown in Figure 3-3. The straws were then packed into sacks for easy transportation to Kampala where the research was conducted. The straws were cut into 5-10 cm in length, the aim of cutting the straws 5-10 cm was to make them as small as possible for easy mixing.

Figure 3-3: Collection of rice straws at Kehong Uganda Industrial Development Ltd

The cut straws were boiled in a solution of sodium hydroxide prepared by dissolving 15g of sodium hydroxide pellets in 1liter of water at about 100^0C for 60 minutes and cleaned in water to remove excess or unreacted Sodium Hydroxide from the surface of the rice straws as shown in Figure 3-4. Water squeezed out of the rice straws; the samples were then dried in sunshine.

Figure 3-4: Boiling and washing of the rice straws

3.3.2 Rice husks

The rice husks were collected from rice mills in Masindi District located in Western region of Uganda. The husks were boiled in a solution of sodium hydroxide prepared by dissolving 15g of sodium hydroxide pellets in 1liter of water at about 100^0C for 60 minutes and were then cleaned in water to remove excess or unreacted Sodium Hydroxide from the surface of the rice husks. Water squeezed out of the husks; the samples were then dried in sunshine.

This treatment was aimed at increasing surface roughness, resulting in better mechanical interlocking; it also aimed at increasing the amount of cellulose exposed on the fibre surface, thus increasing the number of possible reaction sites and fibre/matrix adhesion, it further eliminate weak boundary layers and remove superficial lignin layer.

3.3.3 Cement

Cement is one of the most important building material in today's construction industry. In this research, Ordinary Portland Cement (OPC) 32.5 N, manufactured by Tororo Cement Factory was used as a binder

3.3.4 Water.

According to ASTM C187 (2016) water for concrete should be of portable quality with PH between 6.8 and 8.0. The water used for mixing was clean drinking water. The clean water allows the hydration process of cement to follow its normal course. Drinking water is regarded acceptable for use in mixing concrete. Potable water of National Water and Sewerage Corporation Company (NWSC) from standpipe tap was used for the study.

3.4 Preparation of blocks.

In the manufacture of the blocks, Hand mixing was employed and the materials were turned over a number of times until an even colour and consistency were attained.

Water was added to the mix with water - cement ratio of 0.56 and the mix further turned over to secure adhesion.

Figure 3-5: Preparation of the blocks

The block were cast in moulds of internal dimensions 400 x150 x 200mm, the most used sizes of blocks in Uganda’s construction industry and allowed to set. The blocks were left on pallets under cover in separate rows, one block high and with a space between two blocks for the curing of 7 days period. They were kept wet during the curing period by watering daily.

One hundred twenty one (121) blocks were prepared for this research. Eleven (11) blocks samples of each mix were prepared. These included: six (6) blocks prepared for compressive strength and density test, which were conducted after 7 days and 28 days respectively. Three (3) blocks were prepared for water absorption and fire resistance tests, which were conducted after 28 days. A block was prepared for thermal conductivity test, which was conducted after 28 days of curing. A block was also prepared for conducting Micro Structure examination using Scanning Electron Microscope (SEM). It is summarised in Table 3.1

Table 3-1: Schedule of blocks prepared for the Research

Sample Code	Weight Ratios of Mixture Cement: Sand: Fibre	Compressive Strength /Density		Water Absorption Fire Resistance	Thermal Conductivity	Micro Structure	Total
		7 days	28days	28 days	28 days	28 days	28 days
RS-0	1:4:0	3	3	3	1	1	11
RS-10	1:3.9:0.1	3	3	3	1	1	11
RH-10	1:3.9:0.1	3	3	3	1	1	11
RS-20	1:3.8:0.2	3	3	3	1	1	11
RH-20	1:3.8:0.2	3	3	3	1	1	11
RS-30	1:3.7:0.3	3	3	3	1	1	11
RH-30	1:3.7:0.3	3	3	3	1	1	11
RS-40	1:3.6:0.4	3	3	3	1	1	11
RH-40	1:3.6:0.4	3	3	3	1	1	11
RS-50	1:3.5:0.5	3	3	3	1	1	11
RH-50	1:3.5:0.5	3	3	3	1	1	11
		Total					**121**

3.5 Physical and mechanical properties of blocks

3.5.1 Density determination

This test was conducted using the samples prepared for carrying out compressive strength test. The density (kg/m^3) of each block was calculated by determining the weight (kg) and volume (m^3) by measuring the length, width and thickness. The Density of the blocks was calculated as weight of the block unit divided by the dimensional volume according to BS EN 772-4:1998.

$$\text{Density} = \frac{\text{Mass of Block (kg)}}{\text{Dimensional volume of block(m3)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn 3}$$

3.5.2 Compressive Strength

The compressive strength is an important property of blocks that enables the evaluation of material’s ability to withstand the compressive action on the structure. The value of the compressive strength is strongly influenced by the characteristics of the raw materials as well as by the production process.

Curing was carried out daily by sprinkling the blocks with sufficient water every morning and thereafter, covered with sisal bags. After the first seven days of curing, the blocks were then watered twice a week while still covered with sisal bags, until tested. The compressive strength tests carried out after curing for 7 and 28 days.

Six (6) block samples of each mix were prepared for this test. Compressive strength test carried on the sample blocks to determine the maximum load that the block can withstand. The compressive strength of the blocks were determined according to BS EN12390-3:2019, employing a Universal Testing Machine (UTM).

During the compressive strength test, each block of nominal dimension 400 x 150 x 200 mm was weighed and aligned on the Universal Testing Machine. This was followed by gradual application of load at a rate of 14N/mm^2 per minute till failure. The maximum applied load was recorded and used to calculate compressive strength of the fibrecrete blocks as illustrated in Figure 3-6.

Figure 3-6: Determination of compressive strength of the blocks.

The maximum compressive strength of the individual fibrecrete blocks was evaluated by using equation 5.

$$\text{Compressive Strength} = \frac{\text{Maximum load at failure}}{\text{Contact Area}} \text{ (N/mm2)} \ldots\ldots\ldots\ldots\ldots \text{Eqn 4}$$

3.5.3 Water absorption

Absorption testing is a common method of determining water resistance of the blocks. BS 1881-122:2011+A_1:2020 measure the amount of water that penetrates into block samples when submersed in clean water at room temperature. The water absorption was determined by measuring the amount of water absorbed by a dried sample that had been immersed in water for a specified period (24 hours).

The blocks dried in a ventilated oven at 100-105^{o}C for not less than 24 hours, the blocks were weighed (Md). Blocks were then fully immersed in a water bath, and left there for 24 hours. Blocks were then removed from the water bath after 24 hours and wiped until dry. The saturated and surface dry blocks immediately weighed (Mw).

The water absorption of blocks obtained by equation 5.

$$\text{Water Absorption (\%)} = \frac{M\text{w} - Md}{M\text{d}} x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ Eqn. 5}$$

Where; *Mw* (g) is mass of wet blocks, *Md* (g) is mass of blocks after drying.

The results were expressed as a percentage of the original dry mass of the specimen to the nearest 0.1% of the dry mass.

3.5.4 Thermal Conductivity.

The thermal conductivity of the fibrecrete blocks were determined based on the principle of Hot-wire method using Thermal Conductivity Meter (QTM) as shown in Figure 3-7. This test was conducted at the Department of Physic Makerere University. The hot-wire method is a transient technique that measures temperature increase at a known remoteness from a linear heat source.

Figure 3-7: Determination of thermal conductivity of the blocks in the laboratory.

The probe consists of single heater wire and thermocouple. When constant electric power (energy) is given to the heater, the temperature of the wire rises in exponential progression. Temperature rising curve is plotted in linear line with time axis scaled in logarithm. The angle of this line increases if the sample has less thermal conductivity, and decreases if it has higher thermal conductivity. Therefore, thermal conductivity of a sample can be determined from the angle of the rising temperature graphic line.

Thermal conductivity test was performed using a quick thermal conductivity meter QTM-500 instrument. The QTM-500 instrument has a limiting measuring range of 0.023 w/(mk) to 12 w/(mk) with a precision and reproducibility of ± 5% and ± 3% on reading values respectively. The minimum sample size required for testing is 100 x 50 x 20 mm thickness. Thermal conductivity of materials was tested at a temperature of 25^0C.

3.5.5 Fire Resistance.

For the fire resistance test, three samples of fibrecrete blocks were prepared and cured for 28 days prior to their burning in a furnace at a temperature of 500°C for one hour as shown in Figure 3-8 (Alshahwany et al., 2020). Then, the samples cooled at room temperature in open-air condition for twenty-four hours. The residual compressive strength of the blocks determined according to BS EN 12390-3:2019 employing a Universal Testing Machine (UTM).

Figure 3-8: Firing and determination of residual compressive strength of blocks

3.5.6 Microstructure of the block.

Scanning electron microscopy (SEM) was carried out to establish existence of gaps surrounding the fibre in the fibrecrete blocks. Selected fibrecrete blocks from the different mix proportion were cut to depict the interior parts for the analysis with scanning electron microscope. This test was done according to the test procedure specified in (ASTM C1723, 2016).

The scanning electronic microscope (SEM) controlled via personal computer, with a power dispersing attachment for element microanalysis and vacuum processing of samples. Perfect optical properties, not flickering numeral image of excellent quality at high speed scanning.

Scanning electronic microscope (SEM) analysis running at 10kv was used to study the microstructure of the blocks. The microstructure of the blocks displayed on the monitor, which is connected to the machine at different magnifications ranging from 4-100000 and at different view fields.

Figure 3-9: Determination of microstructure of the blocks.

3.6 Chapter summary

This chapter generally provided the logical steps that were taken in data collection, analysis for achievement of the objectives. It highlighted how this was done and followed. This helped in the subsequent chapters about presentation of findings and discussion.

CHAPTER FOUR: PRESENTATION OF RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents findings of the study conducted to investigate the effects of Rice Husks (RH) and Rice Straws (RS) fibres on the properties of 'lightweight fibrecrete blocks'. The findings are presented according to the objectives of the study.

4.2 Density of the blocks

Table 4-1: Densities of RH/RS blocks.

Curing Period	Density (kg/m^3)					
	CT-0	RH-10	RH-20	RH-30	RH-40	RH-50
7-Days	2144	1988	1871	1770	1677	1519
28- Days	2138	1970	1845	1698	1655	1497
	CT-0	RS-10	RS-20	RS-30	RS-40	RS-50
7-Days	2144	1955	1848	1748	1688	1647
28- Days	2138	1947	1839	1730	1649	1485

The densities of RH blocks varied between 1970- 1497 kg/m^3 while the densities of RS blocks varied between 1947 - 1485 kg/m^3 and control block has density of 2138 kg/m^3 at 28 days. The results as shown in Figure 4.1 and Figure 4.2 indicate a decrease in the densities of both types of fibrecrete blocks as the proportion of rice husk and straws increases. The reduction in the densities of the blocks varied from 7.9 -30 % for RH-blocks, and 8.9-30.5 % for RS-blocks.

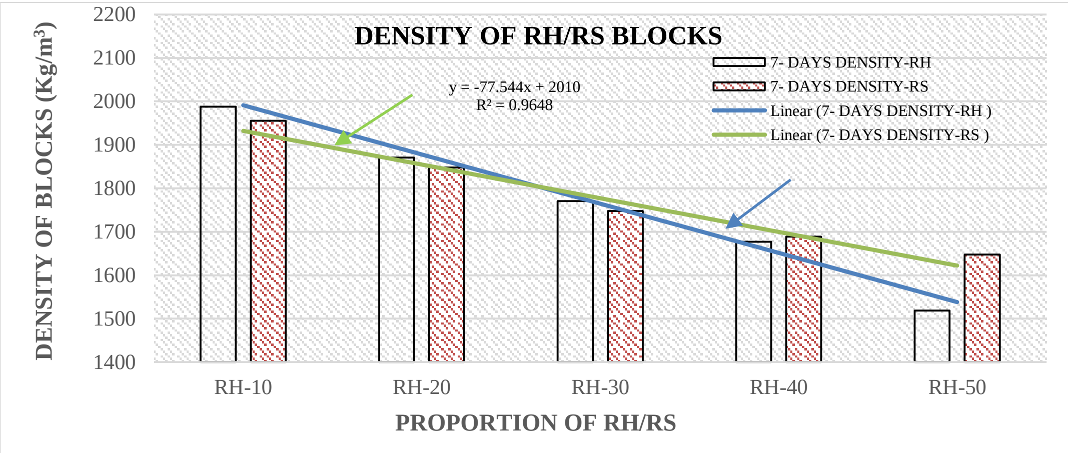

Figure 4-1: Relationship between proportion of fibre and densities of blocks at 7-days

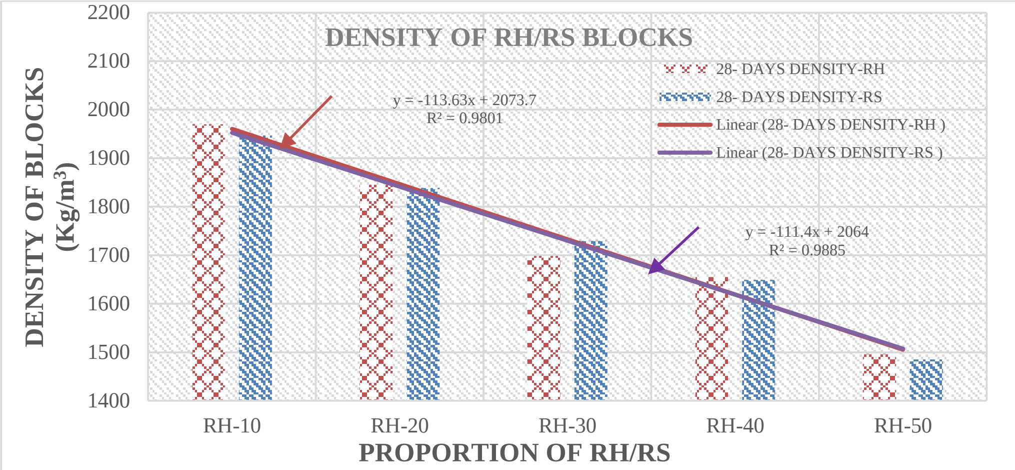

Figure 4-2: Variation of density of blocks with proportion of fibre at 28-days

The statistical analysis, as shown in Figure 4-1 and Figure 4-2 indicates a linear relationship between proportion of RH/RS in the blocks and density of blocks with a negative correlation of 0.9912 for RH and 0.9648 for RS blocks at 7 days and 0.9801 for RH and 0.9885 for RS blocks at 28 days. This indicates that addition of RH and RS have great effect on the densities of the blocks.

The low densities of the blocks was attributed to the high porosity of rice husks and straws that ranges from 63.64-68.94% and 71.21-85.28%, respectively (Zhang, et al., 2012). The porosity inside the composite is proportional to the content of the fibre thus explaining the inverse relationship between densities and the fibre content.

The reduction in the densities is also attributed to incorporation of RH/RS in the blocks as the fibres have low densities. The density of rice husks and straws ranges between 331.59-380.54 kg/m^3 and 162.03-194.48 kg/m^3 respectively (Zhang, et al., 2012).

The reduction in the densities was further attributed to the void created in the blocks as revealed by the microstructure of the blocks as in Figure 4-8, 4-9 and 4-10.

According to Ugandan specification for solid concrete UNBS (2018), solid concrete blocks are grouped into three density grades as; Grade A, density ≥ 2100 kg/m^3; Grade B, 1681 kg/m^3 ≤ density ≤ 2099 kg/m^3 and Grade C, density ≤ 1680 kg/m^3.

As per Table 4-1, blocks of RH-10, RH-20, RH- 30, RS-10, RS- 20, and RS- 30 have densities between 2099 kg/m^3 and 1681 kg/m^3 and are Grade B block while blocks of RH-40, RH- 50, RS-40 and RS- 50 have densities ≤1680 kg/m^3 hence they belong to Grade C blocks.

4.3 Compressive Strength

Table 4-2: Compressive strength of RH/RS blocks

Curing Period	Compressive Strength (N/mm2)					
	CT-0	RH-10	RH-20	RH-30	RH-40	RH-50
7-DAYS	4.75	3.45	2.79	1.93	1.76	0.98
28- DAYS	6.89	5.36	4.29	3.35	2.64	1.53
	CT-0	RS-10	RS-20	RS-30	RS-40	RS-50
7-DAYS	4.75	1.72	0.90	0.83	0.63	0.5
28- DAYS	6.89	3.48	2.95	1.81	1.47	1.28

The compressive strength of RH/RS blocks presented in Table 4-2-show reduction in the strength with increase in proportion of the fibre. This effect was greatly noticed with the RS blocks showing RH blocks have higher compressive strength.

The strength of the fibrecrete blocks increased with increase in day of curing, as shown in Figure 4-3 and Figure 4-4.

Compressive strength of RH blocks as shown in Figure 4-4 ranged between 1.53N/mm^2 for RH-50 to 5.36N/mm^2 for RH-10 while the values for RS-10 and RS-50 were 1.28N/mm^2 and 3.48N/mm^2 respectively at 28 days.

As per the standard specification for building works of Uganda 2012, the minimum compressive strength of blocks is 2.2 (N/mm^2) for the individual blocks and 2.8 (N/mm^2) for average of 10 (ten) blocks.

Similarly BS 6073: part 1-1981 requires minimum compressive strength of 2.8 (N/mm^2) at 28 days with no individual block having compressive strength lower than 80 of that value.

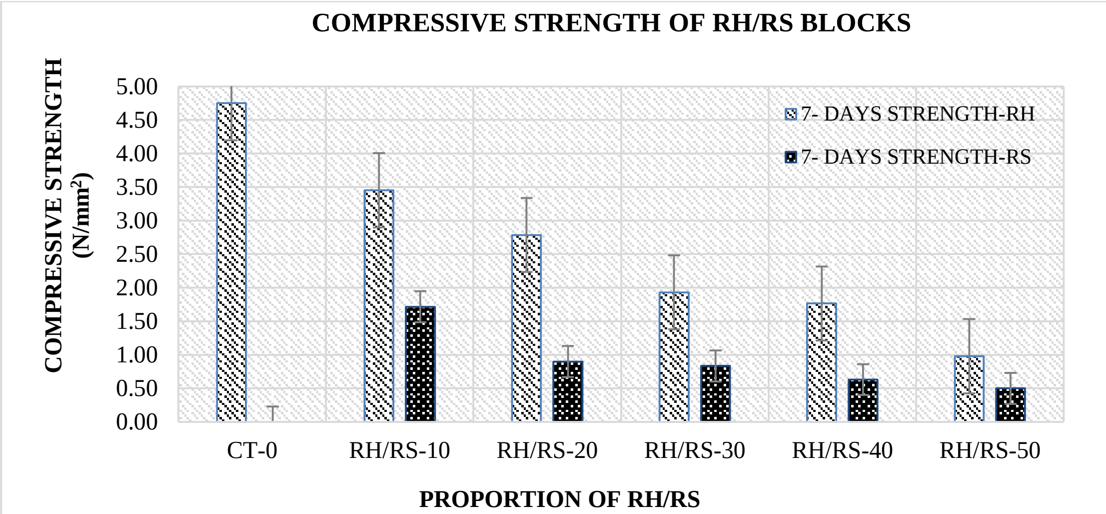

Figure 4-3: Compressive strength of RH/RS blocks at 7 days.

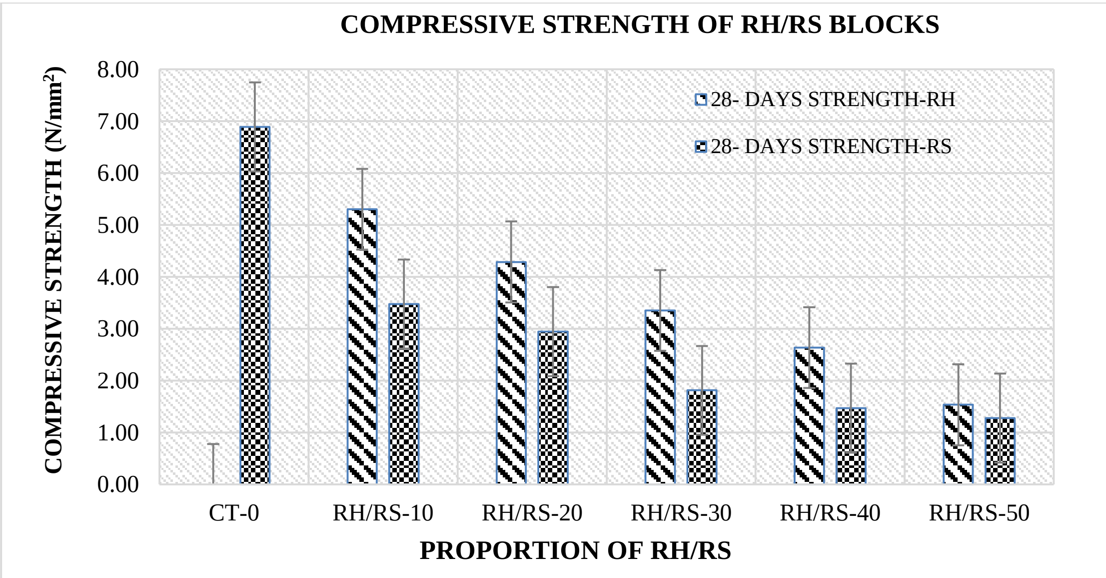

Figure 4-4: Compressive strength of RH/RS blocks at 28-days

4.4 Water absorption

Table 4-3: Water absorption of RH/RS blocks

	Water absorption (%)					
RH-BLOCKS	CT-0	RH-10	RH-20	RH-30	RH-40	RH-50
	3.6	5.8	6.2	6.4	7.4	7.6
RH-BLOCKS	CT-0	RS-10	RS-20	RS-30	RS-40	RS-50
	3.6	6.4	7.5	8.3	9.3	11.3

According to Ugandan specification for solid concrete UNBS (2018), the max water absorption of blocks depends on the density of the blocks. The solid concrete blocks are grouped into three density grades. For grade, A blocks whose density ≥2100 kg/m^3 the maximum water absorption is 11%; Grade B, 1681 kg/m^3≤ density≤2099 kg/m^3 the maximum water absorption is 13%; Grade C, density ≤ 1680 kg/m^3 the maximum water absorption is 17%.

As per Table 4.3 and Figure 4-5, the water absorption for RH/RS for all the proportion are less than 11% (maximum water absorption for blocks whose density is greater than 2100 kg/m^3).

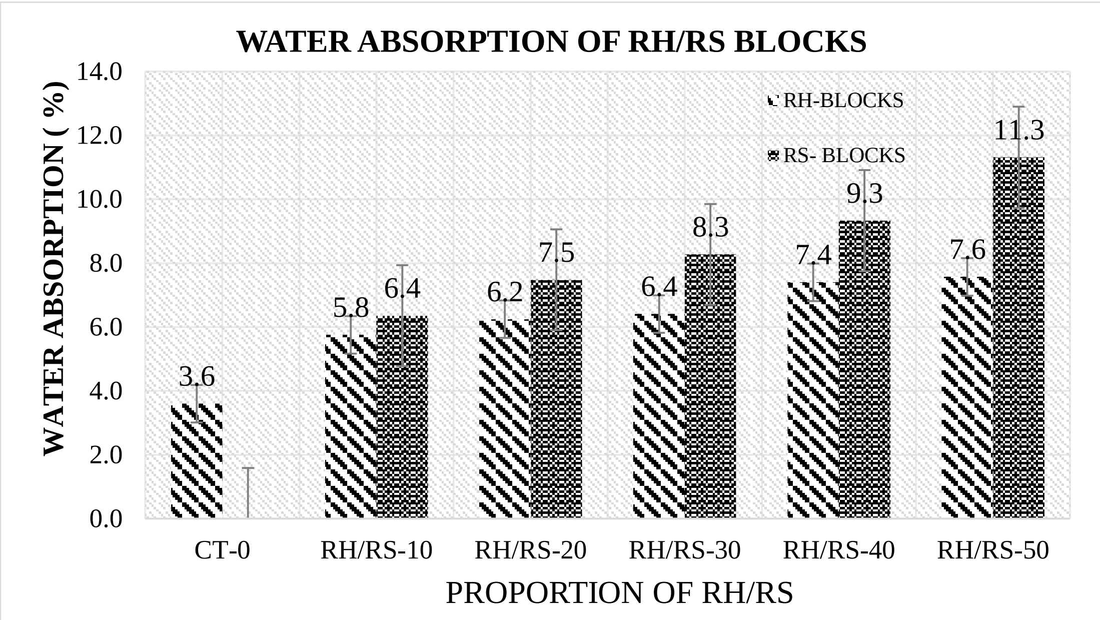

Figure 4-5: Variation of Water absorption of blocks with proportion of RH/RS

4.5 Thermal Conductivity.

Table 4-4: Thermal Conductivity of RH/RS blocks

	Thermal Conductivity (w/mk)					
	CT-0	RH-10	RH-20	RH-30	RH-40	RH-50
RH- Block	1.0059	0.7117	0.6378	0.5190	0.4404	0.3542
	CT-0	RS-10	RS-20	RS-30	RS-40	RS-50
RS-Block	1.0059	0.8710	0.8289	0.6356	0.4597	0.3559

The thermal conductivity test samples were prepared to obtain the value of thermal conductivity of the blocks. The thermal conductivity of the blocks was carried to establish the thermal insulation capacity of the fibrecrete blocks when used for walling. The values obtained from the samples incorporating RH/RS are as shown in Table 4.4.

Table 4.4 and Figure 4-6 indicate that, the thermal conductivity of the blocks decreased as the proportion of the RH/RS increased. The value ranged between 0.8710 w/mk for RS-10 to 0.3542 w/mk for RH-50; these value of thermal conductivity are less than that of the thermal conductivity of control blocks 1.0059 w/mk, thus indicating that RH/RS blocks can transfer less heat per unit time as compared to the control blocks.

In general, the thermal conductivity is an important aspect in buildings. The understanding regarding heat transfer and temperature distribution through the building material can be used for analysis of the energy use and thermal comfort of the building. Good thermal insulation provides thermal comfort without excess air conditioning, which is one of the primary requirements of a building.

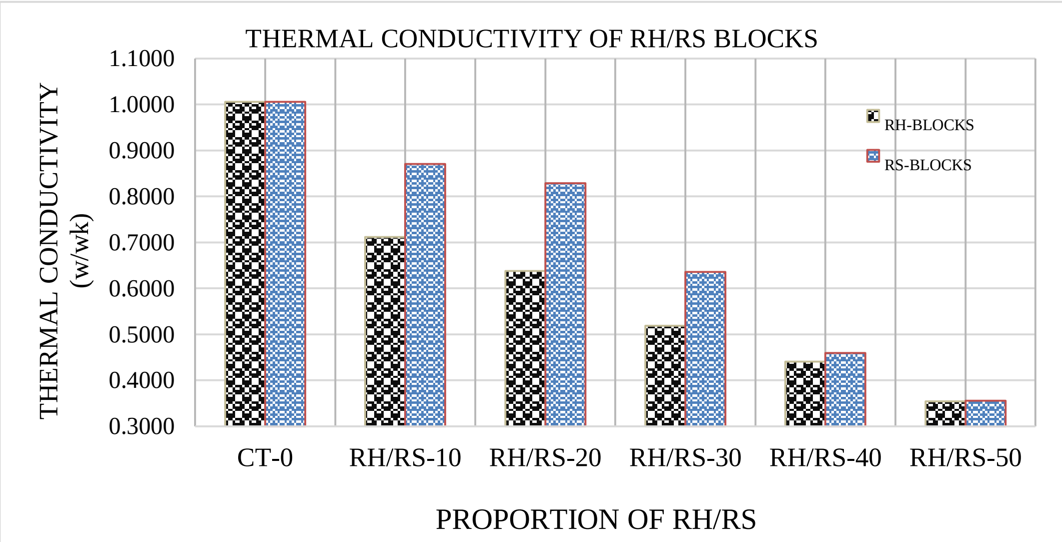

Figure 4-6: Variation of thermal conductivity of blocks with proportion of RH/RS

4.6 Fire Resistance

Table 4-5: Residual compressive strength of fired RH/RS blocks

	Residual compressive strength (N/mm^2)					
	CT-0	RH-10	RH-20	RH-30	RH-40	RH-50
28- DAYS	5.61	4.74	3.43	1.85	1.61	1.01
	CT-0	RS-10	RS-20	RS-30	RS-40	RS-50
28- DAYS	5.61	3.24	1.86	1.07	0.65	0.34

As compared to the unfired blocks the compressive strength of fired blocks are lower than that for the unfired fibrecrete blocks, indicating loss of strength during the process of firing. The percentages for the strength loss in the blocks increased as the proportion of the fibre in the blocks increased with increase in the proportion of fibre in the blocks with values ranging from 10.7% for RH-10, 20.0% for RH-20, 25.9% for RH-30, 30.8% for RH-40 and 34.3% for RH-50. The corresponding value for RS blocks were 6.8% for RS-10, 36.9% for RS-20, 40.7% for RS-30, 56.0% for RS-40 and 73.7% for RS-50. This shows that the quantity of the fibres in the blocks have effects in the compressive strength of fibrecrete block due to firing.

The residual compressive strength of fibrecrete blocks RH-10, RH-20 and RS-10 as shown in Table 4.5 still satisfy the lowest compressive strength of 2.2 N/mm^2 as per standard specification for building works of Uganda 2012.

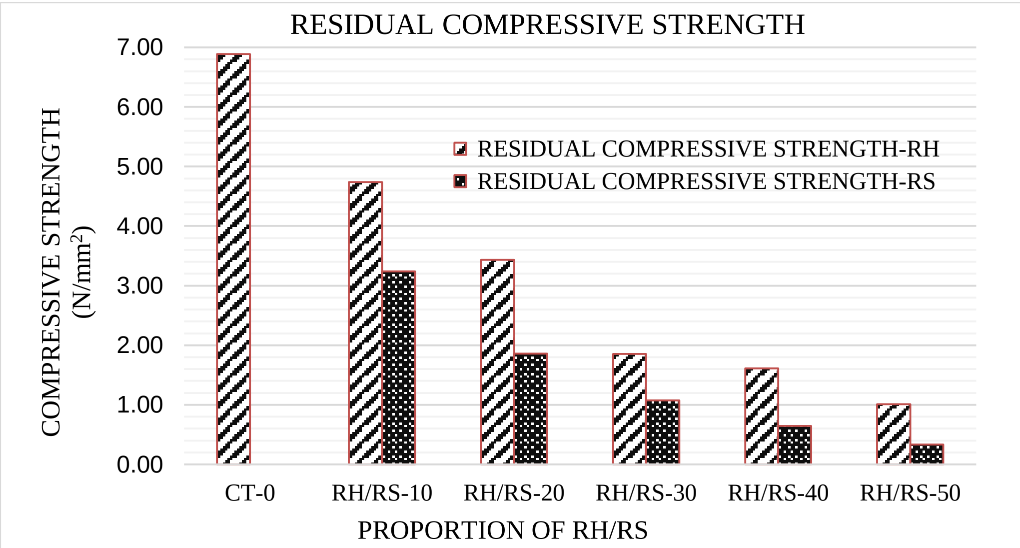

Figure 4-7: Residual compressive strength of fired RH/RS blocks.

4.7 Microstructure of the block

The different microstructures shown in Figure 4-8, CT- Control blocks without cracks and voids. Figure 4.9-Figure 4-10 rice husk blocks with voids surrounding the husks. Figure 4.11- Figure 4-13 rice straw blocks with voids surrounding the straws with micro cracks. Figure 4-9 to Figure 4-13 have voids and cracks. These could explain their better thermal insulation, reduced density, compressive strength and fire resistance.

The micro cracks could be due to volume change of the fibre in the fibrecrete blocks. Uniform volume changes as in the control blocks do not lead to cracking due to relatively free changes of the volume of the elements or structure in all directions.

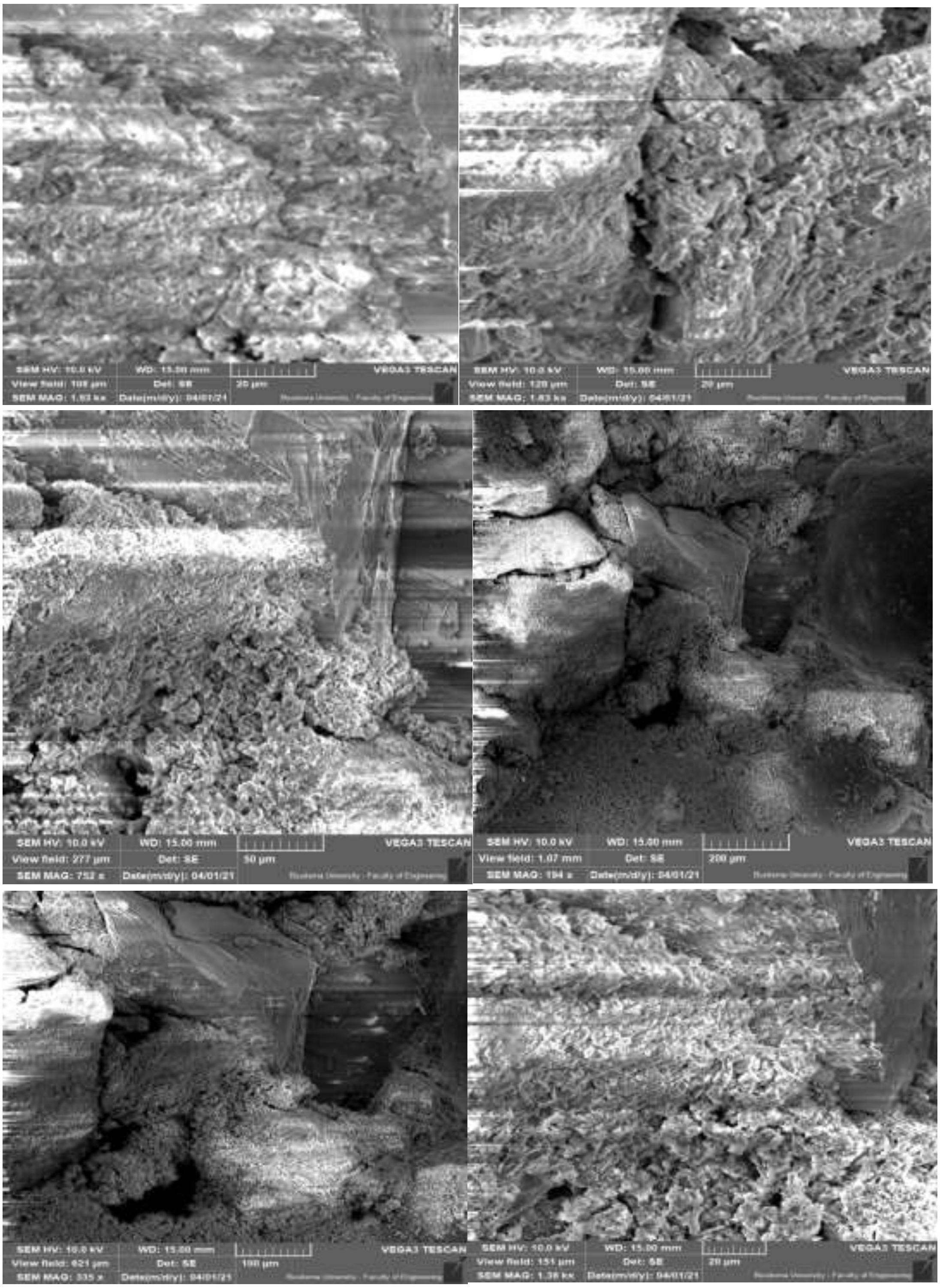

Figure 4-8: Microstructure of blocks without fibre or control blocks

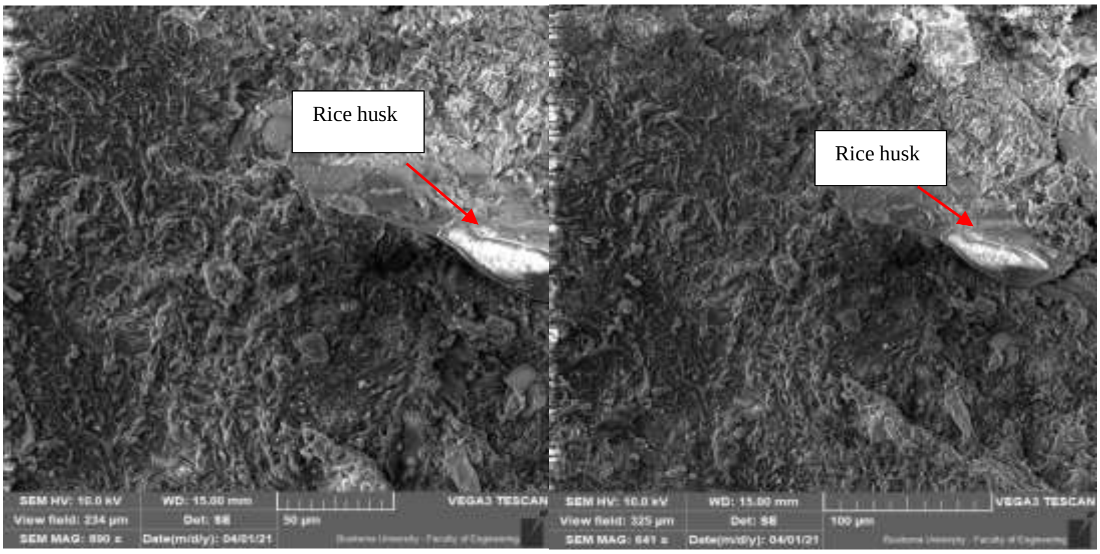

Figure 4-9: Microstructure of RH-30 Blocks

Figure 4-10: Microstructure of RH-50 blocks

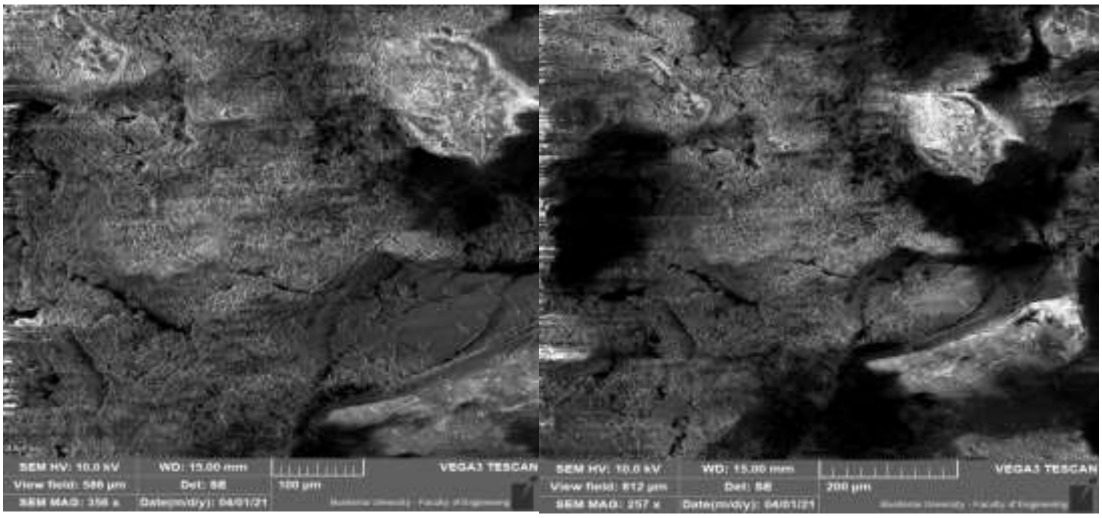

Figure 4-11: Microstructure of RS-10 Blocks

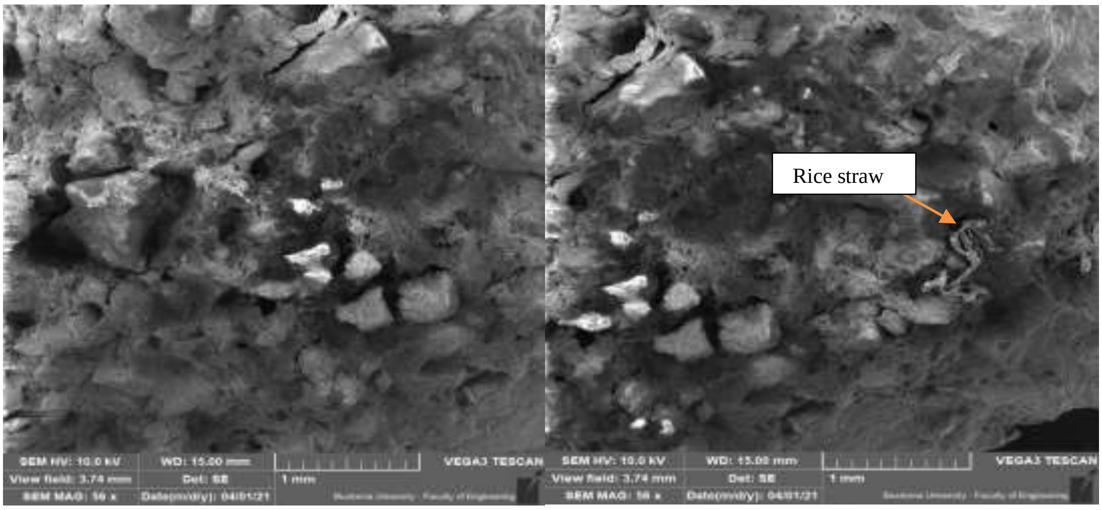

Figure 4-12: Microstructure of RS-30 Blocks

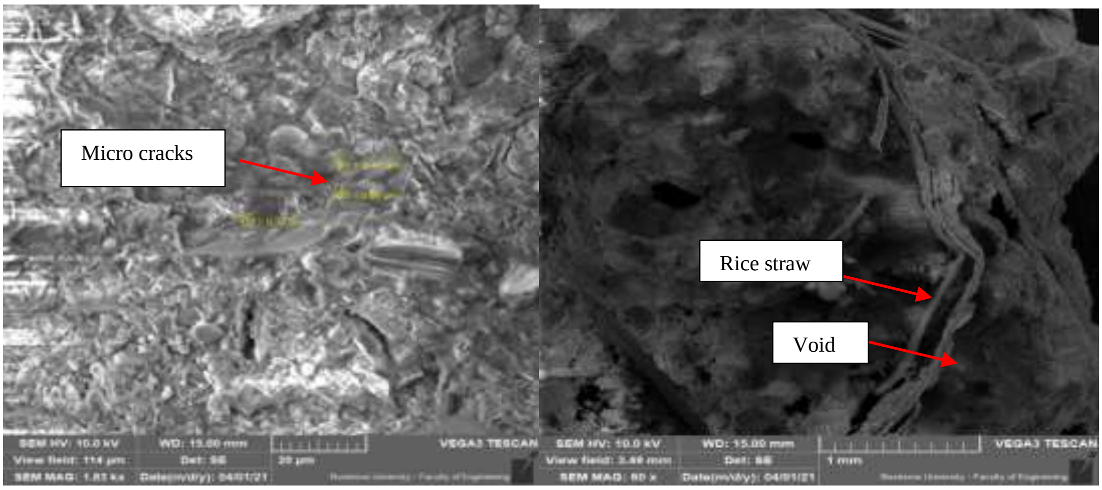

Figure 4-13: Microstructure of RS-50 blocks

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents conclusions and recommendations amassed from action implementation and evaluation presented in chapter four of this report. The conclusions and recommendations were based on the experience, observation and replications, upon the situation as events unfolded in the process of research. Upon discussing and analysing the results, the researcher laid down conclusions based on the results obtained during the research, the learning and understanding acquired by the researcher through the research process. The recommendations laid to reveal the way forward for this research.

5.2 Conclusions

It was established from this research that, the most appropriate mix proportion suitable for production of lightweight fibrecrete blocks was RH-40 with proportions of Cement: Sand : Rice husk fibre of 1:3.6:0.4 and water to cement ratio of 0.56.

In conclusion, the use of rice husks and rice straws in lightweight fibrecrete blocks leads to reduced density, fire resistance, compressive strength, thermal conductivity (increased thermal insulation) and increased water absorption.

It was concluded that, the microstructure of fibrecrete blocks have influence on other properties of fibrecrete blocks, the observations of the microscopic structure of the blocks revealed presence of voids in the fibrecrete blocks. The presence of the voids explains the reduced density, low compressive strength, increased water absorption, and reduced thermal conductivity and fire resistance of the fibrecrete blocks as compared to the control blocks.

5.3 Recommendations.

The recommended lightweight fibrecrete blocks are RH-40 with proportions of 1:3.6:0.4 by weight of cement: sand: rice husk fibre. These have the most appropriate properties for walling, as these proportions meet the minimum compressive strength requirements of Uganda standard specifications, low densities and thermal conductivities.

The study recommended more studies on ways of improving the fire resistance and compressive strength of the fibrecrete blocks without compromising the densities and thermal conductivity.

Although the water absorption of the blocks were within the recommended limits as per Uganda standard specifications. Due to effect of wetting and drying of the blocks, that causes volume changes in the fibres within the block, this can lead to development of micro-cracks in the blocks, and it was further recommended that, these blocks be used for internal walling that is less susceptible to moisture.

The study recommends more research to establish interfacial bond strength between fibres and cement matrix. This can be done by employing pull out techniques of determine the interfacial bond strength for the various combination of fibre and cement matrix.

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APPENDICES

APPENDIX- 1: Densities of RH blocks at 7 days.

	Test No.	**Length (m)**	**Width (m)**	**Height (m)**	**Mass (kg)**	**Volume (m^3)**	**Density (kg/m^3)**
RH-10	1	0.4	0.15	0.2	23.625	0.012	1969
	2	0.4	0.15	0.2	24.132	0.012	2011
	3	0.4	0.15	0.2	23.803	0.012	1984
							1988
RH-20	1	0.4	0.15	0.2	22.322	0.012	1860
	2	0.4	0.15	0.2	22.346	0.012	1862
	3	0.4	0.15	0.2	22.678	0.012	1890
							1871
RH-30	1	0.4	0.15	0.2	21.174	0.012	1765
	2	0.4	0.15	0.2	21.353	0.012	1779
	3	0.4	0.15	0.2	21.208	0.012	1767
							1770
RH-40	1	0.4	0.15	0.2	20.307	0.012	1692
	2	0.4	0.15	0.2	19.87	0.012	1656
	3	0.4	0.15	0.2	20.197	0.012	1683
							1677
RH-50	1	0.4	0.15	0.2	17.943	0.012	1495
	2	0.4	0.15	0.2	18.182	0.012	1515
	3	0.4	0.15	0.2	18.543	0.012	1545
							1519

APPENDIX- 2: Densities of RS blocks at 7 days.

	Test No.	Length (m)	Width (m)	Height (m)	Mass (kg)	Volume (m^3)	Density (kg/m^3)
CT-0	1	0.4	0.15	0.2	25.809	0.012	2151
	2	0.4	0.15	0.2	25.774	0.012	2148
	3	0.4	0.15	0.2	25.595	0.012	2133
							2144
RS-10	1	0.4	0.15	0.2	23.373	0.012	1948
	2	0.4	0.15	0.2	23.342	0.012	1945
	3	0.4	0.15	0.2	23.673	0.012	1973
							1955
RS-20	1	0.4	0.15	0.2	22.173	0.012	1848
	2	0.4	0.15	0.2	22.064	0.012	1839
	3	0.4	0.15	0.2	22.296	0.012	1858
							1848
RS-30	1	0.4	0.15	0.2	21.437	0.012	1786
	2	0.4	0.15	0.2	20.949	0.012	1746
	3	0.4	0.15	0.2	20.537	0.012	1711
							1748
RS-40	1	0.4	0.15	0.2	20.296	0.012	1691
	2	0.4	0.15	0.2	20.354	0.012	1696
	3	0.4	0.15	0.2	20.133	0.012	1678
							1688
RS-50	1	0.4	0.15	0.2	19.494	0.012	1625
	2	0.4	0.15	0.2	19.914	0.012	1660
	3	0.4	0.15	0.2	19.897	0.012	1658
							1647

APPENDIX- 3: Densities of RH blocks at 28 days.

	Test No.	Length (m)	Width (m)	Height (m)	Mass (kg)	Volume (m^3)	Density (kg/m^3)
CT-0	1	0.4	0.15	0.2	25.844	0.012	2154
	2	0.4	0.15	0.2	25.478	0.012	2123
	3	0.4	0.15	0.2	25.638	0.012	2137
							2138
RH-10	1	0.4	0.15	0.2	23.546	0.012	1962
	2	0.4	0.15	0.2	23.618	0.012	1968
	3	0.4	0.15	0.2	23.743	0.012	1979
							1970
RH-20	1	0.4	0.15	0.2	22.184	0.012	1849
	2	0.4	0.15	0.2	21.952	0.012	1829
	3	0.4	0.15	0.2	22.284	0.012	1857
							1845
RH-30	1	0.4	0.15	0.2	20.278	0.012	1690
	2	0.4	0.15	0.2	20.137	0.012	1678
	3	0.4	0.15	0.2	20.724	0.012	1727
							1698
RH-40	1	0.4	0.15	0.2	20.045	0.012	1670
	2	0.4	0.15	0.2	19.775	0.012	1648
	3	0.4	0.15	0.2	19.745	0.012	1645
							1655
RH-50	1	0.4	0.15	0.2	18.159	0.012	1513
	2	0.4	0.15	0.2	18.041	0.012	1503
	3	0.4	0.15	0.2	17.682	0.012	1474
							1497

APPENDIX- 4: Densities of RS blocks at 28 days

	Test No.	Length (m)	Width (m)	Height (m)	Mass (kg)	Volume (m^3)	Density (kg/m^3)
CT-0	1	0.4	0.15	0.2	25.844	0.012	2154
	2	0.4	0.15	0.2	25.478	0.012	2123
	3	0.4	0.15	0.2	25.638	0.012	2137
							2138
RS-10	1	0.4	0.15	0.2	23.197	0.012	1933
	2	0.4	0.15	0.2	23.517	0.012	1960
	3	0.4	0.15	0.2	23.381	0.012	1948
							1947
RS-20	1	0.4	0.15	0.2	21.991	0.012	1833
	2	0.4	0.15	0.2	22.018	0.012	1835
	3	0.4	0.15	0.2	22.178	0.012	1848
							1839
RS-30	1	0.4	0.15	0.2	20.778	0.012	1732
	2	0.4	0.15	0.2	20.872	0.012	1739
	3	0.4	0.15	0.2	20.621	0.012	1718
							1730
RS-40	1	0.4	0.15	0.2	19.629	0.012	1636
	2	0.4	0.15	0.2	19.711	0.012	1643
	3	0.4	0.15	0.2	20.016	0.012	1668
							1649
RS-50	1	0.4	0.15	0.2	18.183	0.012	1515
	2	0.4	0.15	0.2	17.232	0.012	1436
	3	0.4	0.15	0.2	18.044	0.012	1504
							1485

APPENDIX- 5: Compressive strength of RH blocks at 7 days.

	Test No.	Length (m)	Width (m)	Height (m)	Force (kN)	Area (m^2)	Pressure (N/mm^2)
CT-0	1	0.4	0.15	0.2	301.5	0.06	5.03
	2	0.4	0.15	0.2	281.9	0.06	4.70
	3	0.4	0.15	0.2	272.0	0.06	4.53
							4.75
RH-10	1	0.4	0.15	0.2	208.2	0.06	3.47
	2	0.4	0.15	0.2	201.4	0.06	3.36
	3	0.4	0.15	0.2	211.6	0.06	3.53
							3.45
RH-20	1	0.4	0.15	0.2	168.3	0.06	2.81
	2	0.4	0.15	0.2	170.1	0.06	2.84
	3	0.4	0.15	0.2	162.9	0.06	2.72
							2.79
RH-30	1	0.4	0.15	0.2	126.8	0.06	2.11
	2	0.4	0.15	0.2	112.7	0.06	1.88
	3	0.4	0.15	0.2	108.1	0.06	1.80
							1.93
RH-40	1	0.4	0.15	0.2	107.6	0.06	1.79
	2	0.4	0.15	0.2	105.0	0.06	1.75
	3	0.4	0.15	0.2	105.0	0.06	1.75
							1.76
RH-50	1	0.4	0.15	0.2	55.1	0.06	0.92
	2	0.4	0.15	0.2	60.7	0.06	1.01
	3	0.4	0.15	0.2	60.3	0.06	1.01
							0.98

APPENDIX- 6: Compressive strength of RS blocks at 7 days

	Test No.	Length (m)	Width (m)	Height (m)	Force (kN)	Area (m^2)	Pressure (N/mm^2)
CT-0	1	0.4	0.15	0.2	301.5	0.06	5.03
	2	0.4	0.15	0.2	281.9	0.06	4.70
	3	0.4	0.15	0.2	272.0	0.06	4.53
							4.75
RS-10	1	0.4	0.15	0.2	92.7	0.06	1.55
	2	0.4	0.15	0.2	93.7	0.06	1.56
	3	0.4	0.15	0.2	122.5	0.06	2.04
							1.72
RS-20	1	0.4	0.15	0.2	56.2	0.06	0.94
	2	0.4	0.15	0.2	52.7	0.06	0.88
	3	0.4	0.15	0.2	52.8	0.06	0.88
							0.90
RS-30	1	0.4	0.15	0.2	51.7	0.06	0.86
	2	0.4	0.15	0.2	47.2	0.06	0.79
	3	0.4	0.15	0.2	51.2	0.06	0.85
							0.83
RS-40	1	0.4	0.15	0.2	38.6	0.06	0.64
	2	0.4	0.15	0.2	41.7	0.06	0.70
	3	0.4	0.15	0.2	33.2	0.06	0.55
							0.63
RS-50	1	0.4	0.15	0.2	28.9	0.06	0.48
	2	0.4	0.15	0.2	29.7	0.06	0.50
	3	0.4	0.15	0.2	31.3	0.06	0.52
							0.50

APPENDIX- 7: Compressive strength of RH blocks at 28 days.

	Test No.	Length (m)	Width (m)	Height (m)	Force (kN)	Area (m^2)	Pressure (N/mm^2)
CT-0	1	0.4	0.15	0.2	403.2	0.06	6.7
	2	0.4	0.15	0.2	425.5	0.06	7.1
	3	0.4	0.15	0.2	412.3	0.06	6.9
							6.9
RH-10	1	0.4	0.15	0.2	321.4	0.06	5.4
	2	0.4	0.15	0.2	310.6	0.06	5.2
	3	0.4	0.15	0.2	322.7	0.06	5.4
							5.3
RH-20	1	0.4	0.15	0.2	257.5	0.06	4.3
	2	0.4	0.15	0.2	261.7	0.06	4.4
	3	0.4	0.15	0.2	252.3	0.06	4.2
							4.3
RH-30	1	0.4	0.15	0.2	195.5	0.06	3.3
	2	0.4	0.15	0.2	207.4	0.06	3.5
	3	0.4	0.15	0.2	200.3	0.06	3.3
							3.4
RH-40	1	0.4	0.15	0.2	166.3	0.06	2.8
	2	0.4	0.15	0.2	148.9	0.06	2.5
	3	0.4	0.15	0.2	159.4	0.06	2.7
							2.6
RH-50	1	0.4	0.15	0.2	85.3	0.06	1.4
	2	0.4	0.15	0.2	97.4	0.06	1.6
	3	0.4	0.15	0.2	93.5	0.06	1.6
							1.5

APPENDIX- 8: Compressive strength of RS blocks at 28 days.

	Test No.	Length (m)	Width (m)	Height (m)	Force (kN)	Area (m^2)	Pressure (N/mm^2)
CT-0	1	0.4	0.15	0.2	403.2	0.06	6.7
	2	0.4	0.15	0.2	425.5	0.06	7.1
	3	0.4	0.15	0.2	412.3	0.06	6.9
							6.9
RS-10	1	0.4	0.15	0.2	198.3	0.06	3.3
	2	0.4	0.15	0.2	216.4	0.06	3.6
	3	0.4	0.15	0.2	211.3	0.06	3.5
							3.5
RS-20	1	0.4	0.15	0.2	182.4	0.06	3.0
	2	0.4	0.15	0.2	168.0	0.06	2.8
	3	0.4	0.15	0.2	179.7	0.06	3.0
							2.9
RS-30	1	0.4	0.15	0.2	109.2	0.06	1.8
	2	0.4	0.15	0.2	106.7	0.06	1.8
	3	0.4	0.15	0.2	110.2	0.06	1.8
							1.8
RS-40	1	0.4	0.15	0.2	83.6	0.06	1.4
	2	0.4	0.15	0.2	95.9	0.06	1.6
	3	0.4	0.15	0.2	84.7	0.06	1.4
							1.5
RS-50	1	0.4	0.15	0.2	77.7	0.06	1.3
	2	0.4	0.15	0.2	78.6	0.06	1.3
	3	0.4	0.15	0.2	73.7	0.06	1.2
							1.3

APPENDIX- 9: Residual Compressive strength of RH blocks after Firing

	Test No.	Length (m)	Width (m)	Height (m)	Force (kN)	Area (m^2)	Pressure (N/mm^2)
CT-0	1	0.4	0.15	0.2	338.1	0.06	5.64
	2	0.4	0.15	0.2	327.3	0.06	5.46
	3	0.4	0.15	0.2	344.1	0.06	5.74
							5.61
RH-10	1	0.4	0.15	0.2	314.2	0.06	5.24
	2	0.4	0.15	0.2	304.4	0.06	5.07
	3	0.4	0.15	0.2	234.1	0.06	3.90
							4.74
RH-20	1	0.4	0.15	0.2	221.4	0.06	3.69
	2	0.4	0.15	0.2	201.7	0.06	3.36
	3	0.4	0.15	0.2	194.4	0.06	3.24
							3.43
RH-30	1	0.4	0.15	0.2	99.0	0.06	1.65
	2	0.4	0.15	0.2	113.2	0.06	1.89
	3	0.4	0.15	0.2	121.1	0.06	2.02
							1.85
RH-40	1	0.4	0.15	0.2	104.0	0.06	1.73
	2	0.4	0.15	0.2	87.3	0.06	1.46
	3	0.4	0.15	0.2	99.0	0.06	1.65
							1.61
RH-50	1	0.4	0.15	0.2	60.6	0.06	1.01
	2	0.4	0.15	0.2	58.7	0.06	0.98
	3	0.4	0.15	0.2	62.3	0.06	1.04
							1.01

APPENDIX- 10: Residual Compressive strength of RS blocks after Firing

	Test No.	Length (m)	Width (m)	Height (m)	Force (kN)	Area (m^2)	Pressure (N/mm^2)
	1	0.4	0.15	0.2	338.1	0.06	5.64
	2	0.4	0.15	0.2	327.3	0.06	5.46
	3	0.4	0.15	0.2	344.1	0.06	5.74
							5.61
RS-10	1	0.4	0.15	0.2	187.6	0.06	3.13
	2	0.4	0.15	0.2	194.4	0.06	3.24
	3	0.4	0.15	0.2	201.6	0.06	3.36
							3.24
RS-20	1	0.4	0.15	0.2	111.7	0.06	1.86
	2	0.4	0.15	0.2	128.2	0.06	2.14
	3	0.4	0.15	0.2	94.4	0.06	1.57
							1.86
RS-30	1	0.4	0.15	0.2	57.0	0.06	0.95
	2	0.4	0.15	0.2	63.2	0.06	1.05
	3	0.4	0.15	0.2	73.2	0.06	1.22
							1.07
RS-40	1	0.4	0.15	0.2	35.9	0.06	0.60
	2	0.4	0.15	0.2	39.2	0.06	0.65
	3	0.4	0.15	0.2	41.2	0.06	0.69
							0.65
RS-50	1	0.4	0.15	0.2	18.3	0.06	0.31
	2	0.4	0.15	0.2	20.0	0.06	0.33
	3	0.4	0.15	0.2	22.1	0.06	0.37
							0.34

APPENDIX- 11: Water absorption of RH Blocks

	Test No.	Mass of wet blocks (kg)	Mass of blocks after oven drying (kg)	Mass of water absorbed (kg)	Water absorption of the blocks (%)
CT-0	1	26.431	25.347	1.084	4.3
	2	26.212	25.467	0.745	2.9
					3.6
RH-10	1	24.612	23.314	1.298	5.6
	2	24.512	23.136	1.376	5.9
					5.8
RH-20	1	23.134	21.745	1.389	6.4
	2	23.262	21.925	1.337	6.1
					6.2
RH-30	1	22.424	21.123	1.301	6.2
	2	22.332	20.937	1.395	6.7
					6.4
RH-40	1	21.312	19.978	1.334	6.7
	2	21.421	19.811	1.61	8.1
					7.4
RH-50	1	19.512	18.167	1.345	7.4
	2	19.321	17.933	1.388	7.7
					7.6

APPENDIX- 12: Water absorption of RS Blocks

	Test No.	Mass of wet blocks (kg)	Mass of blocks after oven drying (kg)	Mass of water absorbed (kg)	Water absorption of the blocks (%)
CT-0	1	26.431	25.347	1.084	4.3
	2	26.212	25.467	0.745	2.9
					3.6
RS-10	1	24.634	23.112	1.522	6.6
	2	24.413	23.004	1.409	6.1
					6.4
RS-20	1	23.623	22.034	1.589	7.2
	2	23.935	22.214	1.721	7.7
					7.5
RS-30	1	22.546	20.789	1.757	8.5
	2	22.345	20.672	1.673	8.1
					8.3
RS-40	1	21.475	19.546	1.929	9.9
	2	21.588	19.844	1.744	8.8
					9.3
RS-50	1	19.901	17.863	2.038	11.4
	2	19.982	17.967	2.015	11.2
					11.3

APPENDIX- 13: Thermal conductivity of RH/RS Blocks

	Test No.	Thermal Conductivity, (w/mk)		Thermal Conductivity, (w/mk)
CT-0	1	0.9327	CT-0	0.9327
	2	1.0790		1.0790
		1.0059		1.0059
RH-10	1	0.7260	RS-10	0.9111
	2	0.6974		0.8308
		0.7117		0.8710
RH-20	1	0.7278	RS-20	0.8089
	2	0.5477		0.8488
		0.6378		0.8289
RH-30	1	0.4176	RS-30	0.7380
	2	0.6203		0.5331
		0.5190		0.6356
RH-40	1	0.4166	RS-40	0.4160
	2	0.4642		0.5034
		0.4404		0.4597
RH-50	1	0.3453	RS-50	0.2921
	2	0.3631		0.4197
		0.3542		0.3559

APPENDIX- 14: Introduction Letter to Busitema University

KYAMBOGO UNIVERSITY

Department of Civil and Environmental Engineering

P. O. BOX 1, KYAMBOGO – KAMPALA, UGANDA

TEL: +256-41-4287340, FAX: +256-41-4289056/4222643

29th March 2020

THE DEAN,
FACULTY OF ENGINEERING
BUSITEMA UNIVERSITY

RE: INTRODUCTION LETTER FOR MR. ABAZA LEO REG: NO 18/U/GMES/22114/PE

This is to introduce the above-named final year student who is undertaking a Master of Science in Structural Engineering at the Faculty of Engineering, Department of Civil and Environmental Engineering, Kyambogo University. Abaza is undertaking a research study titled: **"INVESTIGATING THE EFFECTS OF RICE HUSK AND RICE STRAWS ON THE PHYSICAL AND MECHANICAL PROPERTIES OF LIGHTWEIGHT FIBRECRETE BLOCKS"** This is one of the requirements for graduation at Kyambogo University to conduct research and submit a dissertation/thesis by graduate students before awarding them a degree. One of the properties to be determined is the microstructure of the blocks.

The purpose of this communication is to humbly request your office to assist him access your laboratory facilities and the relevant staff to provide any other guidance to help him successfully conduct his research at your organisation. The information will only be used for academic purposes and shall be kept confidential. We thank you in advance for your cooperation and we hope the findings of this research will also benefit the organisation.

Yours faithfully,

KYAMBOGO UNIVERSITY HEAD OF DEPARTMENT 29 MAR 2021 DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING

Dr. Muhwezi Lawrence
Head of Department,
Civil and Environmental Engineering
Kyambogo University

APPENDIX- 15: Introduction Letter to Makerere University

KYAMBOGO UNIVERSITY
Department of Civil and Environmental Engineering
P. O. BOX 1, KYAMBOGO – KAMPALA, UGANDA
TEL: +256-41-4287340, FAX: +256-41-4289056/4222643

29th March 2020

THE HEAD,
PHYSICS DEPARTMENT
MAKERERE UNIVERSITY

RE: INTRODUCTION LETTER FOR MR. ABAZA LEO REG: NO 18/U/GMES/22114/PE

This is to introduce the above-named final year student who is undertaking a Master of Science in Structural Engineering at the Faculty of Engineering, Department of Civil and Environmental Engineering, Kyambogo University. Abaza is undertaking a research study titled: **"INVESTIGATING THE EFFECTS OF RICE HUSK AND RICE STRAWS ON THE PHYSICAL AND MECHANICAL PROPERTIES OF LIGHTWEIGHT FIBRECRETE BLOCKS"** This is one of the requirements for graduation at Kyambogo University to conduct research and submit a dissertation/thesis by graduate students before awarding them a degree. One of the properties to be determined is thermal conductivity of the blocks.

The purpose of this communication is to humbly request your office to assist him access your laboratory facilities and the relevant staff to provide any other guidance to help him successfully conduct his research at your organisation. The information will only be used for academic purposes and shall be kept confidential. We thank you in advance for your cooperation and we hope the findings of this research will also benefit the organisation.

Yours faithfully,

KYAMBOGO UNIVERSITY HEAD OF DEPARTMENT 29 MAR 2021 DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING

Dr. Muhwezi Lawrence
Head of Department,
Civil and Environmental Engineering
Kyambogo University

Mr. ABAZA tested his samples from physics dept on 29/03/2021.

MAKERERE UNIVERSITY HEAD 29 MAR 2021 DEPARTMENT OF PHYSICS P.O. BOX 7062, KAMPALA (U)