UNIVERSITY OF EDUCATION WINEBA

COLLEGE OF TECHNOLOGY EDUCATION, KUMASI

INVESTIGATION INTO THE PROPERTIES OF COMPRESSED EARTH BRICKS STABILIZED WITH COW DUNG AND REINFORCED WITH PALM FRUIT FIBRES

ALEXANDER OWUSU ANSAH

DECEMBER 2021

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200007683

A THESIS IN THE DEPARTMENT OF CONSTRUCTION AND WOOD TECHNOLOGYEDUCATION, FACULTY OF TECHNICAL EDUCATION, SUBMITTED TO THESCHOOL OF GRADUATE STUDIES, UNIVERSITY OF EDUCATION WINEBA, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE MASTER OF PHILOSOPHY (CONSTRUCTION TECHNOLOGY) DEGREE.

DECEMBER, 2021

DECLARATION

CANDIDATE'S DECLARATION

I, ALEXANDER OWUSU ANSAH hereby declare that this dissertation is my own original research. Except quotations and references contained in published works (which have all been identified and acknowledged). The entire dissertation is my own original work, and it has not been submitted, either in part or whole for another degree elsewhere.

SIGNATURE………………………………..

DATE ………………………………………

SUPERVISOR'S DECLARATION

I, hereby declare that the preparation and presentation of this dissertation were supervised in accordance with guidelines and supervision of the dissertation laid down by the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development

DR. EMMANUEL APPIAH - KUBI

SIGNATURE……………………………….

DATE ………………………………………

DEDICATION

I dedicate this research work to the Almighty God through whose protection and grace, I have been able to reach this far in my education. Also, I cannot conclude this work without mentioning the people who gave meaning to my life, my family, especially my dear wife Mrs. Cecilia Owusu -Ansah and my children Theresah Owusu-Ansah Ryan and Obrempong Owusu-Ansah.

ACKNOWLEDGEMENT

With deep gratitude and joy, I acknowledge the God Almighty, who made it possible for me to commence and conclude this research work.

I thank my supervisor, DR. EMMANUEL APPIAH - KUBI at the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development who assisted me right away from the initial conception of the idea, through the thick and thin up to the final stage, giving me relevant pieces of advice from time to time and making appropriate suggestions and recommendations, which enriched the quality of this research work.

I also extend my warmest gratitude and appreciation to all authors whose ideas are recognized.

I also acknowledge the efforts of Mr Adam Wahab who also assisted me from time to time.

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ABSTRACT

Using Agro-waste to reinforce earth bricks has been encouraged by many researchers these days. In this study, the properties of compressed earth bricks reinforced with cow dung (CD) and palm fruit fibres (PFF) were investigated. Experiments were conducted to determine the particle size distribution, fibre aspect ratio, density, water absorption, compressive strength, tensile strength, and abrasion resistance of the specimens. Materials used for the study were earth, palm fruit fibres (PFF), cow dung (CD), and water. The particle size distribution was done according to BS EN 1377-1. Water used for the study was conformed to BS EN 1008. The materials for the study were mixed manually and moulding of the specimens was done mechanically by a compressed hydraulic brick moulding machine of mould size 100mm X 100mm X 130mm. The specimens were cured using the air-drying method for 28 days. The number of specimens used for the study was 150. The density and compressive strength of the specimen was determined in accordance with BS EN 772-1. Water absorption was also determined in accordance with BS EN 772-11. Split tensile strength test was determined using BS EN 12390-6 as a guide. The abrasion resistance of the specimens was determined using the surface wire brushing method. Data obtained were analysed using Microsoft Excel v.15 and presented using descriptive and inferential statistics.

It was revealed that the density of specimens decreased with increasing CD and PFF content, while the water absorption of the specimens increased with increasing CD and PFF content. Additionally, the study revealed that the compressive strength, split tensile strength abrasion resistance decreased with increase in CD and PFF content. One-Way ANOVA analysis revealed that there are no significant differences between the control bricks and those reinforced with CD and PFF in terms of the compressive strength and the split tensile strength of the specimens. Therefore, the study recommends that compressed earth bricks reinforced with cow dung and palm fruit fibres should be used for non-load-bearing walls.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Accommodation is one of the basic needs of every human being (Afrane et al., 2016). The construction of inexpensive housing for citizens has become a major problem for many countries including Ghana. According to Danso and Manu (2013), the provision of inexpensive structures and accommodation for the people is constrained due to the high price of conventional building materials such as cement and mild steel rods. Also, the demand for building materials has increased in the construction industry which has caused a shortage of building materials (Madurwar et al., 2013). There is a need to adopt cost-effective building materials such as earth, clay, and wood to build sustainable structures.

It is well understood that sustainable construction is one of the most crucial issues in the world in recent days which requires constructing a building in such a way that every individual will have a comfortable home without consuming or depleting available natural resources. According to the eleventh sustainable development goal (SDG11) which states that, making cities and human settlements inclusive, safe, resilient, and sustainable with a target aiming at supporting least developed countries, through financial and technical assistance, building sustainable and resilient building utilizing local materials. It is believed that using local materials such as clay, earth, natural fibres, wood, and bamboo for building purposes reduces embodied energy. For example, the energy required to produce cement-based materials (concrete and sandcrete blocks) is significantly higher than the energy required to produce earth-based materials such as compressed earth bricks. Therefore, the study of local building materials for the construction of affordable houses has become the focus of many researchers in many studies. Examples can be found in the strength and durability properties of cow dung stabilized earth brick (Yalley and Manu, 2013). The study of Yalley and Manu (2013) revealed that the compressive strength of bricks stabilized with 20% of cow dung content increased about 25% over the earth brick without stabilizer. Danso et al. (2015) studied on physical, mechanical, and durability properties of soil building blocks reinforced with coconut, oil palm and bagasse fibres. It was revealed that 0.5% fibre content in clayey soil has improved physical, mechanical, and durability properties of the blocks over unreinforced blocks without fibre content. Danso et al. (2015) researched into effect of sugarcane bagasse fibre on the strength properties of soil blocks and found that 0.5% of sugarcane bagasse fibber content in soil blocks enhanced the strength properties of the soil blocks over unreinforced blocks.

Earth is common in most communities in Ghana, thereby making it readily available for construction purposes. It has been revealed in many studies that, the earth is one of the many alternative materials that can be used for the construction of buildings (Yalley and Manu, 2013). However, earth-based materials such as compressed earth bricks have some drawbacks such as shrinkage, high water absorption, and cracks as compared to normal sandcreate blocks. Cow dung has been one of the causes of environmental pollution in many communities where cattle rearing is common, thereby creating adverse environmental impacts such as landfills, air pollution, and water pollution in our society and the entire nation as a whole. A study by Yalley and Manu (2013) on the strength and durability properties of cow dung stabilized earth brick revealed that bricks stabilized with 20% cow dung content have lower penetration of water than plain earth bricks without cow dung content. People in rural areas in Ghana especially the Northern part of the country use cow dung for plastering of walls and screeding to improve thermal insulation properties in their buildings.

It has also been realized that the palm-oil industry produces large amounts of agro wastes such as palm fruit fibre, palm kernel shells, and palm empty fruit bunches. Palm fruit fibre (PFF) wastes are mostly used as a domestic fuel for cooking in most communities. Also, many societies in Ghana use palm fruit fibres to reinforce the earth to construct traditional earthen oven to improve its strength. Additionally, some villagers use palm fruit fibre to stabilize the earth to construct traditional tripod stove to enhance its durability properties. Furthermore, Adegoke et al. (2019) investigated on utilization of palm fruit fibres as constituent materials for hand mould clay bricks. The study of Adegoke et al. (2019) reveals that as the quantity of palm fruit fibres increases the compressive strength of the bricks also increases.

Though a lot of studies have been done on investigating the properties of compressed earth bricks, a lot of studies focused on using palm fruit fibres as reinforcement, while cow dung was also used as a stabilizer. This study will combine the palm fruit fibres as reinforcement and cow dung as a stabilizer.

Therefore, the purpose of the study was to investigate the properties of compressed earth bricks stabilized with cow dung and reinforced with palm fruit fibres.

1.2 Statement of the problem

Cow dung has been one of the causes of environmental pollution in many communities where cattle rearing is common, thereby creating environmental impacts such as landfills, air pollution, and water pollution in our society and the entire nation as a whole.

When cow dung is heaped at a particular place for a long period as a way of disposing it, when it rains the water washes the cow dung into river bodies and contaminates the water which poses danger to human consumption and aquatic species. Cow dung dump on the environment creates land fill which makes it difficult to use the land for other purposes such as land development. Additionally, Continuous disposal of cow dung produces methane emission which causes air pollution thereby posing danger to human health and also constitutes a nuisance to the environment as well as a blemish to the public (Lasisi & Ojomo, 2018).

The volume of cow dung produced from the rearing of cattle is speedily cumulative over time due to the high demand for cattle rearing, however, the environmental impact associated with cow dung will continue if measures are not put in place to utilize cow dung.

As a way of utilizing cow dung, research has shown that cow dung can be added to earth to produce compressed earth bricks to improve thermal properties, water absorption, tensile strength, and compressive strength of earth bricks, examples can be found in a strength and durability properties of cow dung stabilized earth brick by Yalley and Manu (2013).

It has also been realized that palm-oil industries produce a large quantity of agro wastes such as palm fruit fibre, palm kernel shells, and palm empty fruit bunches. Palm Fruit fibres (PFF) wastes are mostly used as a domestic fuel for cooking in most communities. Burning of PFF as a way of disposing of it releases carbon into the atmosphere which threatens human life, also indiscriminate dumping of PFF on the environment causes environmental problems such as landfill and choked drains.

As a way of utilizing it, research has shown that palm fruit fibres can be added to earth to produce compressed earth bricks to enhance the properties of the bricks, an example can be seen in the properties of coconut, oil palm, and bagasse fibres as potential building materials by Danso (2017).

Though a lot of studies have been done on investigating the properties of compressed earth bricks, a lot of studies focused on using palm fruit fibres as reinforcement, while cow dung was also used as a stabilizer. However, this study will combine the palm fruit fibres as reinforcement and cow dung as a stabilizer.

1.3 Aim of the study

This study aims at examining the properties of compressed earth bricks stabilized with cow dung and reinforced with palm fibres.

1.4 Objectives of the study.

The objectives of the study are;

1. To determine the physical properties (particle size distribution, fibre aspect ratio, density, and water absorption) of compressed earth bricks stabilized with cow dung (CD) and reinforced with palm fruit fibres (PFF).
2. To determine the mechanical properties (compressive strength, split tensile strength and abrasion resistance) of compressed earth bricks stabilized with cow dung (CD) and reinforced with palm fruit fibres (PFF).
3. To determine the durability property (abrasion resistance) of compressed earth bricks stabilized with cow dung (CD) and reinforced with palm fruit fibres (PFF).

1.5 Research Questions

The following research questions were formulated to address the problem statement:

1. What will be the physical properties (density and water absorption) of compressed earth bricks stabilized with cow dung (CD) and reinforced with palm fruit fibres (PFF)?
2. What will be the mechanical properties (compressive strength, split tensile strength and abrasion resistance) of compressed earth bricks stabilized with cow dung (CD) and reinforced with palm fruit fibres (PFF)?
3. What will be the durability property (abrasion resistance) of compressed earth bricks stabilized with cow dung (CD) and reinforced with palm fruit fibres (PFF)?

1.6 Significance of the study

The outcome of the study will help the society to use cow dung and palm fruit fibre that is being wasted to reinforce compressed earth bricks which contribute to the production of environmental pollution.

Moreover, the findings of the study would also add to the existing knowledge of literature and would serve as reference material for future researchers.

The findings of the study would also help many nations which are financially and resource-challenged to adopt the use of agricultural bi-products such as cow dung and palm fruit fibre to put up affordable houses.

1.7 Organization of the thesis

This study was organized into six (6) chapters. Chapter one (1) comprises background of the study, statement of the problem, the aim of the study, objectives of the study, research questions, significance of the study, and organization of the study. Chapter two consists of other researchers' published opinions or views of the topic under discussion. Chapter three (3) describes the experimental materials and procedure used in the study. Chapter four (4) comprises results. Chapter five (5) consists of discussions. Finally, chapter six (6) consists of summary of findings, conclusion, recommendations and suggestions for further studies.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter of the study explored the relevant and related literature in support of the study.

2.2 Earth building construction

Earth has been used as a building material in every continent and every age, largely due to its versatility and widespread availability, and it is one of the oldest building materials. The use of earth on-site as a building material saves manufacturing cost, time, energy, environmental pollution, and transportation cost (Vyncke et al., 2018). Possibly one of the first homes man lived in after he came out of a cave was made of earth. The oldest manmade earth constructions known were found in Mesopotamia, and date from 10 000 BC (Vyncke et al., 2018). According to Yalley and Manu (2013) the earth is one of the many alternative materials that can be used for the construction of buildings. Earth is regaining interest as a building material, not only in developing countries, where due to its abundance and low cost it is a logical and interesting building material for constructing superstructures, but also in modern societies where for reasons of sustainability and limiting transport it has an important advantage opposed to the conventional building materials (Vyncke et al., 2018). This has made researchers continue to research earth bricks as potential building materials.

Conventional building materials production consumes a high amount of energy which has an adverse impact on the environment (Jannat et al.,2020). The authors argue that the use of locally available materials and the upgradation of traditional techniques can be a good option for sustainable development. Consequently, earth has attracted the attention of researchers as a building construction material for its availability and lower environmental impact. On the other hand, in developing countries waste disposal from the agricultural and industrial sectors raises another serious concern. Scientists have introduced such waste additives into the earth matrix to improve its performance.

Accommodation deficit

Accommodation crises is one of the biggest problems around the world, especially in developing countries like Ghana.

Building new houses such as apartments, factories, offices, hospitals, clinics and schools is the responsibility of the building industry (Danso and Manu, 2013). The authors argue that the construction of roads, bridges, ports, railroads, sewers and tunnels, among many other things, are also done by the building construction sector. And also maintains and repairs all of those structures mentioned above and produces the basic building materials such as blocks, bricks and cement. It makes a significant contribution to the national economy and employs a large number of people. The authors further reported that shelter has been a major challenge to individuals, families, groups and governments since urban civilization started. This issue has often been attributed to land acquisition problems and the high cost of building materials among others (Aliyu et al., 2017).

The Population and Housing census conducted in Ghana in 2000 indited that, Ghana is facing an acute accommodation challenge with a housing deficit of over 1.5 million units (Mahama and Adarkwah, 2006). Also, the 2010 population and housing census in Ghana showed that the total population of Ghana was 24,658,823. This rapid population growth and its associated increasing or uncontrolled urbanization have made housing one of the most critical economic issues facing Ghana.

Ghana statistical service (2010) also reported in the 2012 population and housing census that Ghana is facing an accommodation deficit of 2 million. A critical analysis of the situation shows that Ghana’s housing deficit is a problem which is fuelled by many factors such as the cost of building materials, rapid population growth, urbanization, deterioration of the fabric of existing structures, absence of a clear sustainable housing delivery policy framework and poor managerial system (Adinyira et al., 2010).

Many authors have conducted various types of research with the aim of assessing the role of the private sector in the provision of affordable housing. Prominent among these were those conducted by Aribigbola, 2011 who carried out research on the performance of private developers in housing provision in Nigeria.

2.3 Earth bricks stabilization

Due to some drawbacks of earth bricks such as shrinkage, high water absorption, and cracks as compared to normal sandcreate blocks, a lot of studies have been done to look for suitable materials such as palm fruit fibre, corn husk ash, and cow dung to stabilize earth bricks to construct affordable houses. Examples can be found in the strength and durability properties of cow dung stabilized earth brick (Yalley and Manu, 2013).

2.4 Utilization of agro-based materials in brick production

The agricultural industry such as pineapple processing industries, coconut processing industries, and sugar industries produce huge quantities of agricultural wastes such as coir pith waste, coffee husk, and biogases that are a danger to the environment (Yasodha, 2018).

Palm fruit fibres (PFF) are organic waste materials obtained from palm oil processing industries in Ghana. It has also been realized that palm-oil industries produce a large quantity of agro wastes such as palm fruit fibre, palm kernel shells, and palm empty fruit bunches. Palm Fruit fibres (PFF) wastes are mostly used as a domestic fuel for cooking in most communities. Burning of PFF as a way of disposing of it releases carbon into the atmosphere which threatens human life, also indiscriminate dumping of PFF on the environment causes environmental problems such as landfill and choked drains. Also, many societies in Ghana use palm fruit fibres to reinforce the earth to construct traditional earthen oven to improve its strength. Additionally, some villagers use palm fruit fibre to stabilize the earth to construct traditional tripod stove to enhance its durability properties. This environmental issue has motivated a lot of researchers to investigate the utilization of agro-based materials in brick production for the construction of affordable houses. An example can be seen in the utilization of palm fruit fibres as constituent materials for hand mould clay brick (Adegoke et al., 2019).

Danso & Obeng-Ahenkora (2018) reported that the depletion of natural resource and environmental pollution caused by construction activities can be reduced if the construction industry incorporates sustainable construction materials for building development. This can be achieved by modifying and incorporating agricultural waste materials such as palm fruit fibres in earth brick production. The construction activities and the production of building materials such as iron rods, cement, and roofing sheets have caused a serious environmental impact on the atmosphere since the industrial revolution started in many years.

Kadir et al. (2017) argue that agro waste is waste produced from various agricultural activities such as farming that contributes to the large production of waste. They also reported that every year 1.2 million tonnes of agricultural waste are disposed into landfill and 998 million tonnes of agricultural waste is produced per year in Malaysia. The authors further reported that large production of agro waste such as palm fibre (PF), nut shells, palm kernel and empty fruit bunch which was obtained from palm oil extraction has created a major disposal problem, thus affecting the environment.

2.5 Carbon emissions from conventional building materials production

Releasing of Carbon dioxide (CO2) and other gases into the atmosphere have been increasing globally due to human activity such as the burning of fossil fuel and the manufacturing of building materials. It is known that increasing levels of carbon emissions into the atmosphere could produce higher global temperatures and changes in rainfall patterns.

It is well understood that emissions of carbon dioxide play an important role in the natural greenhouse in the atmosphere but the extent to which increases in its concentration might increase global warming (Zhong and Joanna, 2013).

Globally the construction industry contributes the highest carbon emission into the atmosphere as a result of the production of conventional building materials such as cement, aluminium roofing sheets, steel rod, and etc about 40% (Mercado et al., 2019). Furthermore, the rapid speed of construction development contributes to excessive carbon emissions apart from the operational emissions of construction facilities, clients and built environment professionals are concerned about the carbon emissions embodied in construction materials.

According to Pomponi and Moncaster, (2020) the built environment puts the maximum pressure on the natural environment than all the industrial sectors. Also, the international energy agency reports (2021) reported that building-related emissions are on track to double by 2050.

In recent days, promoting, enhancing, and reducing the development and the use of building materials with low carbon and services has become the focus of researchers in many studies these days. An example can be seen in the carbon emission of the global construction sector by Lizhen et al. (2015). The authors also reported that low embodied carbon building material and services, the energy efficiency of construction machines, as well as renewable energy use are the three main crucial chances to reduce the carbon emissions of the construction sector.

2.6 Properties of stabilized earth bricks

The properties of earth bricks /blocks have been classified into the following headings, namely physical properties, mechanical properties, durability properties.

2.6.1 Physical properties

The physical properties of brick include density and water absorption.

Due to some drawbacks of earth bricks, various studies have been conducted to improve the physical properties of earth bricks such as density and water absorption. An example can be seen in the physical, mechanical, and durability properties of soil building blocks reinforced with natural fibres (Danso et al., 2015).

2.6.1.1 Water absorption

The water absorption test is done to determine the percentage of water absorbed by the materials such as brick and concrete.

According to the study by Danso et al. (2013) as the fibre content increased the water absorption of the reinforced soil blocks increased. Danso et al. (2013) further described that the increase in water absorption might be attributed to the amount of water absorbed by the cellulose of the fibres, which was due to the void volume and the amount of cellulose material present in the blocks. The porous nature of fibres created a pathway through soil blocks, thereby allowing more water to be absorbed by the blocks.

Yalley and Manu (2013) also investigated into strength and durability properties of cow dung stabilized with earth brick. The author reported on water absorption that as the quantity of cow dung increases up to 20% stabilization the water absorption declined. This implies that 20% cow dung content gave minor penetration of water into the brick (i e. lower permeability). Yalley and Manu (2013) further explained that the addition of cow dung up to 20% finally led to higher hydrated cow dung and higher mortar content. The higher mortar content makes the brick with some amount of cow dung less porous and more impermeable than the earth matrix, probably by infilling the voids and displacing some of the earth with far less permeable cow dung hydration products, thereby reducing paths for water ingression. Yalley and Manu (2013) again described that increasing cow dung content above 20% did not improve the water absorption of the bricks.

Additionally, Vodounon et al. (2019) investigated on split tensile strength, physical and durability properties of cement stabilized earth block reinforced with treated and untreated pineapple leaf fibre. Their report on water absorption revealed that all the cement stabilized blocks reinforced with Treated Pineapple Leaf Fibre (T-PALF) had less water absorption as compared to blocks reinforced with Untreated Pineapple Leaf Fibre. The study revealed that the T-PALF absorbed less water than N-PALF.

They further observed that the stabilized blocks with 5% of cement content had less water absorption compared to those stabilized with 3% of cement.

Zievie and Yalley (2016) also investigated on evaluation of the strength properties of soil bricks produced with processed African locust bean wastewater as a stabilizer. They found that as the African locust bean wastewater (ALBWW) increased, the water absorption of the brick decreased. This shows that the higher the (ALBWW) content in soil brick the less the water absorption. Zievie and Yalley and Manu (2016) additionally reported that a percentage increase in ALBWW content would reduce the water permeating into the soil bricks by 8.6%.

Furthermore, Adogla et al. (2016) investigated Improving Compressed Laterite Bricks using Powdered Eggshells. Their results revealed the water absorption by capillarity. This test investigated the ability of the bricks specimen to absorb water after partially immersing them in water for 10 minutes. The authors reported that as the eggshells increased from 0% to 30% the water absorption rose slightly. They further reported that increasing eggshells could account for the decreasing volume of voids that were filled with the eggshell particles, therefore, reducing the absorptivity of the bricks. It could also be affiliated with the increasing calcium ions which tend to improve the cementing properties within the soil matrix similar to that of conventional lime.

Danso et al. (2015) also researched into effect of Sugarcane Bagasse Fibre on the Strength Properties of soil blocks. They found that as the quantity of the fibre content increased the water absorption of the soil blocks increased, which confirms the study by Danso et al. (2013) on water absorption. Danso et al. (2015) also explained that the high water absorption of reinforced soil blocks may be attributed to the amount of water absorbed by the cellulose of the fibres, which is due to the void volume and the amount of cellulose material present in the blocks coupled with capillary action.

Furthermore, Asiedu and Yalley (2013) studied enhancing the properties of soil bricks by stabilizing with Corn Husk Ash. They indicated that all the blocks studied absorbed water by capillarity, but the blocks enhanced with cone husk ash up to 20% had low water absorption coefficient, and blocks without any stabilizer recorded high water absorption coefficient. According to the authors, the total water absorbed by the soil blocks gradually declined as the quantity of corn husk ash increased, the soil blocks with 20% addition had the least water absorption coefficient (2.65g/cm2min) while the blocks without corn husk ash (control group) recorded the highest water absorption coefficient (46.35g/cm2min). Their results confirmed previous findings (Yalley and Manu, 2013; Vodounon et al., 2019; Zievie and Yalley, 2016) that the quantity of enhancers affects the water absorption properties of soil bricks.

Asiedu and Yalley (2013) also explained that the decrease in water penetrability was a result of the reduction of pore spaces as the finer particles of the corn husk ash filled the voids thereby drastically reducing the flow of water within the soil blocks or could be attributed to the increase in the pH value of the moulding water as a result of the partial dissociation of the calcium hydroxide.

Danso (2017) investigated the properties of compressed earth blocks stabilized with a Pidiproof liquid waste (P.L.W). The author reported results on the water absorption coefficient test that an average absorption coefficient of about 15, 12, 10, and 9 kg/ (m^2×min) were obtained respectively for 0, 0.5, 1, and 1.5% Pidiproof LW+ contents after 28-day curing. There was about 17, 29, and 42% reduction in absorption coefficient respectively for 0.5, 1, and 1.5% chemical contents in the compressed earth block as compared to the unstabilized specimen. This implies that the higher the inclusion of the chemical content in the compressed earth block the lower the absorption coefficient as Yalley and Manu (2013) and Asiedu and Yalley (2013) recorded similarly. It means that the inclusion of the liquid chemical in the block improved the resistance of water absorption of the blocks. This is in agreement that the use of Pidiproof LW+ reduces the permeability of water into a matrix, and therefore functions similarly in the soil blocks.

Millogo et al. (2018) studied earth blocks stabilized by cow dung. Concerning water absorption, they reported that the earth without cow-dung was dissolved when they were dipped in water, while blocks with cow-dung stabilization content did not dissolve. The authors also explained that the presence of cow dung in earth blocks mix enhanced the resistance of earth to water because of the formation of insoluble silicate amine which glues isolated soil particles together. The material thus became less porous, according to SEM studies of adobes, and resistant to water. In consequence, the presence of cow dung in the clay mixes drastically reduced the water sensitivity of adobes and the harmful impact of water on their mechanical behaviour.

Ige et al. (2022) experimented characterization of adobe bricks stabilized with rice husk and lime for sustainable construction. They reported on water absorption that the absorption coefficient of the rice husk and lime stabilized adobe specimens increased with increased rice husk content. The bricks recorded absorption coefficient from 0.15 to 0.29 kg/m^2 min (0%–1% rice husk content) for RH 28-day sun-dried bricks and from 0.06 to 0.13 kg/m^2 min (0%–1% rice husk content) for RH + L 28-day cured bricks. This indicates that the higher the rice husk content, the lower the water resistance of the rice husk and lime stabilized adobe specimens. There was about a 48% water absorption rate of rice husk stabilized adobe specimens without lime (RH) than the control specimens.

Fundi et al. (2018) investigated the characteristics of interlocking stabilized lateritic clay soil block walls. The authors reported that the water absorption of clay soil blocks increased with an increase in the in cow dung content but reduced stabilizing with cement and lime. The high absorptivity by cow dung stabilized blocks could be attributed to voids introduced by the fibrous nature of cow dung. They also found that there was also no measurement obtained in most RHA stabilized clay soil blocks. The blocks dissolved in water due to the high porosity introduced in the blocks by RHA. Again, they reported that the fibres increase water absorption as the absorbent nature of fibres creates pathways through soil blocks, thereby allowing more water absorption. A similar observation was made by Kwadwo and Evans (2015) in their investigation of the improvement of earth bocks for low income communities in Ghana. The addition of 3% lime to clay soil at specified 5% cement reduced the water absorption by the blocks to the lowest value of 12.06%. The decrease has been explained by Musa (2008) to be a result of the formulation of cementitious compounds by calcium from lime which fills the soil voids thereby obstructing the flow of water. The findings of their study were also consistent with the findings of Guettala et al (2002) who found that increase in lime content from 5% to 12% decreased the water absorption capacity of clay blocks. However, there was an increase in water absorption beyond the 3% lime dosage level resulting in to fully disintegration of blocks in water. The authors finally reported that lime performed better in clay soil stabilization, therefore it should be used together with other stabilizers.

Kadir et al. (2017) conducted research on a feasibility study on the utilization of palm fibre waste in fired clay brick. They reported on water absorption of fired clay bricks manufactured with palm fibres that as the palm fruit content increased, the value of water absorption also increased. The values of the water absorption of the specimens varied from 12.84 % to 18.76 % depending on the percentage of waste containers. The authors also reported that the control specimen tends to absorb lower water with 12.84 % compared to reinforced specimens. Their study also revealed that increasing the amount of palm fibre waste from 1 % to 10 % had increased water absorption of brick ranging from 15.34 %, 18.67 % and 18.76 % respectively. The explanation of this behaviour could be related to the organic matter in palm fibre waste which has been eliminated during the sintering process thus creating numerous pores. These numerous pores filled with water during immersion could lead to an increase in water absorption, especially for PF10 %.

Based on reports given by various studies on water absorption it is clearly shown that soil stabilization with natural pozzolanic materials influences water absorption properties both positively and negatively.

2.6.1.2 Density

It is believed that the density of earth bricks depends on the type of pozzolana used in the production of the bricks, and this has attracted many researchers to study a lot of materials such as cow dung, eggshells powder, and palm fibres that can be used to improved density of earth bricks/blocks. An example can be found in the study on the strength and durability properties of cow dung stabilized earth brick by Yalley and Manu (2013). Yalley and Manu (2013) found that as the quantity of cow dung content increases up to 20 %, the density of the stabilized brick also increases from 1748 kg/m^3 for the un-stabilized brick to1910 kg/m^3, an increment of about 9%.

Danso et al. (2013) also studied on physical, mechanical, and durability properties of soil building blocks reinforced with natural fibres. The results of their study revealed that as the amount of fibre content increased the density of the reinforced soil blocks decreased. The decrease in density was between 7 - 9% for red (R) soil and 6 - 8% for brown (B) soil. The drop in density was expected as fibres have a low density of 810 – 500 kg/m compared to compressed soil density of about 1780 kg/m, and therefore increased fibre content displaced soil content, which is heavier, so decreased the density of the blocks. Red (R) soil blocks had a higher density than brown (B) soil blocks, which might be due to the higher OMC of the soil or the higher clay content.

Also, Vodounon et al. (2019) investigated on split tensile strength, physical and durability properties of cement stabilized earth block reinforced with treated and untreated pineapple leaf fibre. The study reported that the density of the blocks reduced as the quantity of fibre content increased, which supports the study by Danso et al. (2013) that increasing fibre content reduces the density of syllabized earth blocks. Vodounon et al. (2019) observed that the dry density of the blocks ranged between 1827.3 and 2074.0 kg/m3. Additionally, they reported that the densities of blocks stabilized with 5% cement were higher than those stabilized with 3% of cement, and this occurred because of packing density (the fraction of a volume filled by a given collection of solids). In this study 5% of cement filled better the empty spaces in the blocks compared to those stabilized with 3% of cement, hence 5% of cement increased the density of the blocks. A similar observation has been made by Raj et al. (2017) in which the density of earth stabilized blocks increased with an increase in cement content. On the other hand, it was also observed that the density of the blocks decreased with an increase in fibre content. The density was higher for blocks reinforced with treated fibres as compared to those reinforced with non-treated fibres. This may be explained by the hydrophilic properties of the fibre because the treated fibre absorbed less water compared to non-treated ones.

Additionally, Zievie and Yalley (2016) evaluated the strength properties of soil bricks produced with processed African locust bean wastewater as a stabilizer.

the authors reported that the mean densities of the bricks ranged from 2120kg/m3 for soil bricks without African locust bean waste water (ALBW) content to 2167kg/m3 for soil bricks with ALBW content stabilization. This means that as the African locust bean waste water (ALBW) is increasing in the mix the density of the brick is also increasing.

Danso et al. (2015) researched into effect of sugarcane bagasse fibre on the strength properties of soil blocks. The results of the study obtained from the dry density test revealed that the mean dry density of the reinforced soil blocks reduced as the quantity of sugarcane bagasse fibre content increased. A similar trend was obtained in a study by Ismail and Yaacob (2011) and Vodounon et al. (2019) as the density of the blocks reduces when the quantity of fibre content increased. According to a study by Danso et al. (2015), the unreinforced (control group 0%) blocks dry density had the highest density of all the reinforced blocks.

Danso (2017) conducted on the experimental investigation on the properties of compressed earth blocks stabilized with a Pidiproof liquid waste (P.L.W). The study by Danso (2017) on the Density of compressed earth blocks stabilized with the liquid chemical, revealed that the minimum dry density of 1943 kg/m^3 and maximum 2101 kg/m^3 of the stabilized compressed earth blocks as compared to the average dry density of 2052 kg/m^3 of the unsterilized compressed earth block. The values show that there was a little difference between the dry density of compressed earth blocks stabilized with different liquid chemical contents. This means that different contents of chemical inclusion and curing age does not influence the density of compressed earth blocks. This might be attributed to the fact that the chemical used for the stabilization was a liquid and would not affect the mass of the blocks after drying.

According to Adogla et al. (2016) bricks used in the study had their densities within the range of 1500kg/m^3 – 2400kg/m^3 as specified by BS 6073-1 (1981) for dense aggregates masonry units. The results of the study by Adogla et al. (2016) clearly showed that the dry density of the bricks increased steadily as the eggshell content increased. The reason for the increased in density in the presence of the egg shell was due to some pozzolanic action of the egg shell.

Kadir et al. (2017) reported on the dry density of fired clay bricks manufactured palm fibres that the increasing amount of palm fibre waste from 1 % to 10 % had decreased the dry density of brick with 1825.3 kg/m^3, 1729.4 kg/m^3 and 1581.5 kg/m^3 respectively. It is found that palm fibre waste is high in the organic matter thus the easily burned during the sintering process. The result found that all the densities in this study are over 1000 kg/m^3 as recommended by BS EN 772-1 (2003). The authors finally reported that even though the values obtained in this study are highly lower and could be advantageous in the construction field as a lightweight fired clay brick.

Based on reports given by various studies on the density of bricks it is obvious that soil stabilization with natural pozzolanic influences both density and water absorption either positively or negatively.

Bunyamin and Mukhlis (2020) reported in their study that the density of concrete with water cement ratio (w/c) of 0.40 without using oyster shell grain was 2472 kg/m3 while the value for mixture with 5%, 10%, and 15% oyster shell grain decreased to 2427 kg/m3, 2419 kg/m3, and 2422 kg/m3, respectively. The density of concrete with w/c of 0.50 without using oyster shell grain was 2461 kg/m3, while the value for mixture with 5% oyster shell grain increased to 2464 kg/m3. Meanwhile, the mixture's concrete density with 10% and 15% oyster shell grain decreased to 2437 kg/m3 and 2424 kg/m3, respectively. The density of concrete with w/c of 0.60 without using oyster shell grain was 2451 kg/m3 while the value for mixture with 5%, 10%, and 15% oyster shell grain decreased to 2445 kg/m3, 2434 kg/m3, and 2420 kg/m3, respectively.

Olowu et al. (2014) the authors revealed in their study that the densities of brick samples appreciate with age of brick samples and the concentration of zycosil water solution (ZWS) used in its preparation. The densities of improved stabilized lateritic brick (ISLB) appreciate from 2014.78 kg^3 at 7 days to 1916.26kgm^3 at 28 days; while the densities of (Control Stabilized Lateritic Bricks) CSLB appreciate from 1995.07kgm^3 at 7 days to 1926.11kgm^3 at 28 days. The densities of adobe unstabilized lateritic brick (AULB) appreciate from 1908.87kgm^3 at 7 days to 1800.49kgm^3 at 28 days.

2.6.2 Mechanical properties of earth bricks

The mechanical properties of brick include compressive strength, tensile split strength and abrasion resistance.

2.6.2.1 Compressive strength

The Compressive strength of a brick is the ability of the brick to resist or withstand compression. Many studies have been conducted to look for binders that can be used to reinforce earth bricks to increase the compressive strength of a brick. An example can be seen in improving compressed laterite bricks using powdered eggshells by Adogla et al. (2016). The results of the research by Adogla et al. (2016) on Compressive strength revealed that as the eggshells powder quantity was increased in the mix the compressive strength also increased.

Their results also showed that after 28 days of curing age, only compressed laterite bricks with 20% and 30% eggshell content met the acceptability limit for masonry purposes as stipulated by GS 297-1 (2000). As the curing age increased, only laterite without eggshells failed to meet the recommended minimum compressive strength of 2.5N/mm^2. The study also revealed that the increase in the strength characteristics with increasing eggshells was attributed to the calcium ions which react with the clay to form a cementitious matrix thus improving the bond between the soil particles.

Yalley and Manu (2013) investigated into strength and durability properties of cow dung stabilized with earth brick. The result of the study revealed that the compressive strength after immersing the bricks in water for 10 minutes was reduced by an average of 67% for cow dung stabilized samples compared to the compressive strength of samples in their dry state. Furthermore, complete disintegration of un-stabilized specimens was observed a few minutes after immersion in water. Again, bricks with 20% cow dung content as stabilizers had the highest wet compressive strength of 2.76 MPa. Specimens with cow dung content above 20% did not give any significant improvement in the strength of the wet samples. The lower strength of the wet samples could be prevented by treating the surface with cow dung render, polymers, or cow dung– lime renders, especially when the construction is to be exposed to water.

Danso et al. (2013) also studied the physical, mechanical, and durability properties of soil building blocks reinforced with natural fibres. Their study revealed that the compressive strength of the reinforced soil blocks increased with fibre content up to between 0.25 wt.%, and 0.5 wt %, then started declining. Yalley and Manu (2013) reported a similar trend of increasing compressing strength in his studies as the cow dung content increased up to 20% and thereafter the compressive declined. Danso et al. also reported that the increase in compressive strength from unreinforced soil blocks to the optimum was 42 %, 41%, and 21%, respectively for oil palm, coconut, and bagasse fibre-reinforced for red soil blocks. while the increase for brown soil was 53%, 57 %, and 18%, respectively for oil palm, coconut and bagasse fibres reinforced soil blocks. Red soil obtained better optimum strength than brown soil reinforced soil blocks, while brown soil obtained the highest increase of reinforced over the unreinforced blocks. The increase in strength could be linked to increased friction between the fibre and the soil matrix. Furthermore, the association of fibres and the soil matrix prevents the spread of cracks in the blocks, as fibres form bridges across cracks and therefore contribute to the improved strength. Conversely, after a critical point, the increased fibre content caused strength reduction when fibres began to knot and overlap each other, resulting in reduced bonding with the soil and break-up of the soil matrix causing the soil-fibre composite to weaken. It is also likely that the presence of more pores due to increased fibre content in the soil matrix could lead to a reduction in strength.

Danso et al. (2015) reported that the compressive strength of the blocks increased with increasing fibre content until it reached 0.5%, and then decreased with further increase in fibre. This confirms the previous study by Danso et al. (2013) which revealed that compressive strength increased as the fibre content in the mix increased up to 0.25 percent. This indicates that the reinforced soil blocks obtained an optimum compressive strength with about 26% and 19% increase over the unreinforced blocks respectively for soil R and soil B. This means peak strength was obtained along with the fibre mix ratios.

Furthermore, Asiedu and Yalley (2013) studied enhancing the properties of soil bricks by stabilizing them with corn husk ash. The authors reported that the compressive strength of soil blocks with 15% and 20% corn husk ash had compressive strengths being 17.72% and 27.2% higher than soil blocks with no corn husk ash (control group). They found that increasing the corn husk ash in the soil blocks improved the compressive strengths as there was an increase in the formation of compounds possessing cementitious properties that bound the particles together in their study.

Nkrumah and Dankwah (2016) recycled blends of rice husk ash and snail shells as a partial replacement for Portland cement in building block production. They found that compressive strength generally increased with curing age and decreased with an increased amount of rice husk ash and snail shells are added. The results at 14th day showed a percentage increase of 6.15 %, 10.6 %, 88.36 % and 27.45 % for control (0 %), 20 %, 25 % and 30 % partial cement replacement, respectively from the 7th day. However, there was a decrease in compressive strength for the 5 %, 10 %, 15 % and 50% replacement with values 33.57 %, 14.71 %, 19.57 %, 10.6 4%, 26.26 % respectively. The results on the 14th day indicated that pozzolanic action had commenced as evident from the higher percentage increase in compressive strength by the 20%, 25%, and 30% replacement. However, the control still had the highest compressive strength at this age. But the 25 % replacement gave the highest percentage increase in compressive strength. The result can be attributed to the right requirement of the silica in the block formed in the 20 %., 25 %, and 30% replacement to react with water during the hydration of cement to increase the compressive strength. This then confirms the observation by Oyetola and Abdullahi (2006) that for a lower percentage replacement level of 10 % and 20 % RHA the silica from the pozzolana is in the required amount, which aids the hydration process to produce blocks with high compressive strength. Therefore 20 %, 25 % and 30 % had a right requirement of silica in the blocks formed.

Zievie and Yalley (2016) investigated on evaluation of the strength properties of soil bricks produced with processed African locust bean waste water as a stabilizer. From the results of the study, it was seen that compressive strength gradually increased as the African locust bean waste water (ALBWW) content increased, this confirms the study by Danso et al. (2017), Asiedu and Yalley (2013), Yalley and Manu (2013). A compressive strength of 2.38N/mm^2, 3.29N/mm^2, 3.53N/mm^2, and 3.95N/mm^2, were obtained for the specimens (control), 25% (ALBWW), 50% (ALBWW) and 100% (ALBWW) content respectively. The compressive strength of stabilized specimens increased by 66% over the un-stabilized specimens when the soil was fully mixed with African locust bean waste water for bricks production.

Rayaprolu and Raju (2012) also researched into the incorporation of cow dung ash (CDA) into mortar and concrete. They computed the compressive strength of cubes as per IS: 456-2000. By adding various percentages of CDA to cement the strength of concrete decreased while increasing the ash percentage. The compressive strength was calculated by taking an average of three cubes for each 10%, 20%, and 30% percentage. Their study showed that for 10% of added cow dung ash, the average compressive strength has 23.1 N/mm^2,17.44, N/mm^2, and 15.25 N/mm^2 for 28,14,7 days respectively. Similarly, by adding 20% of cow dung ash to cement the average strength was 11.3N/mm^2, 9.15N/mm^2, and 6.53N/mm^2. Finally, by adding 30% of cow dung ash to cement the average strength was 5.81 N/mm^2, 5.44 N/mm^2, and 4.06 N/mm^2.

Ige et al. (2022) reported on a compressive strength test that all the stabilized adobe specimens obtained improved compressive strength from 0% rice husk content to reach a peak strength at 0.75% rice husk content, after which the compressive strength declined to 1% rice husk content. They also reported that at 0.75% rice husk and lime content, the average compressive strengths of the adobe specimens were 3.93, 4.58, and 5.17 MPa, respectively for rice husk (RH) 28-day sun-dried bricks, rice husk and lime (RH + L) 7-day cured bricks, and rice husk and lime (RH + L) 28-day cured bricks. A similar trend of the result was achieved by Araya-Letelier et al. (2018), who reinforced adobe blocks with pig hair, and Tran et al. (2018), who reinforced cemented soil with cornsilk fibres. This means the inclusion of natural fibres in the adobe specimens helps to improve the compressive strength. There was about 66%, 80%, and 86% improvement in compressive strength, respectively, for RH 28-day sun-dried bricks, RH + L

7-day cured bricks, and RH + L 28-day cured bricks between the 0% and the 0.75% rice husk contents. The reason for the improved strength up to the peak is associated with apparent interlocking force within the bricks due to increased friction and bond strength between the rice husk and the soil. Another reason is the cohesion created between the matrix and the rice husk improved with the inclusion of rice husk, and the performance was further improved by the addition of lime. The result implies that the addition of 0.75% rice husk and lime significantly improved the compressive strength of the adobe specimens.

Kadir et al. (2017) reported on the compressive strength of fired clay bricks manufactured with palm fibres that as the PF content increased, the value of compressive strength is decreased. They revealed that 1% palm fibres (PFB) obtained the highest compressive strength with 19.56 MPa followed by control specimens with 19.52 MPa. Meanwhile, compressive strength for PFB5 % was recorded as 9.78 MPa followed by PFB10 % with 4.13 MPa. It is expected that PFB10 % contained high organic matter thus leaving pores inside the brick and reducing the strength of the brick. Compressive strength is an important parameter to ensure the engineering quality of bricks to withstand loads.

Nkrumah and Dankwah (2016) studied the recycling blends of rice husk ash and snail shells as a partial replacement for Portland cement in building block production. They reported that the effect of curing ages on the compressive strength of building blocks increased with curing age and decreased with an increased amount of rice husk ash and snail shells added. They also reported that results at 14th day showed a percentage increase of 6.15 %, 10.6 %, 88.36 % and 27.45 % for control (0 %), 20 %, 25 % and 30 % partial cement replacement, respectively from the 7th day. However, there was a decrease in compressive strength for the 5 %, 10 %, 15 % and 50% replacement with values 33.57 %, 14.71 %, 19.57 %, 10.6 4%, 26.26 % respectively. The authors further reported that on the 14th day the results indicated that pozzolanic action had commenced as evident from the higher percentage increase in compressive strength by the

20 %, 25 % and 30% replacement. However, the control still had the highest compressive strength at this age. But the 25 % replacement gave the highest percentage increase in compressive strength. The result can be attributed to the right requirement of the silica in the block formed in the 20 %, 25 % and 30% replacement to react with water during the hydration of cement to increase the compressive strength. This then confirms the observation by Oyetola and Abdullahi (2006) that for a lower percentage replacement levels of 10 % and 20 % RHA the silica from the pozzolana is in the required amount, which aids the hydration process to produce blocks with high compressive strength.

Bunyamin and Mukhlis (2020) studied on utilization of oyster shells as a substitute part for cement and fine aggregate in the compressive strength of concrete. They reported that the compressive strength of concrete with a water-cement ratio of 0.40 without using oyster shell recorded was 31 MPa, while specimen with 5% oyster shell recorded 32 MPa. The authors further reported that, the specimen with 10% and 15% oyster shell decreased again to 31 MPa and 27 MPa, respectively. They also reported that the compressive strength of concrete with w/c of 0.50 without using oyster shell grain was 28 MPa, while the value for mixture with 5% and 10% oyster shell grain increased to 33 MPa and 29 MPa, respectively, and the compressive strength of specimen with 15% oyster shell decreased to 25 MPa. Also, the compressive strength of concrete with w/c of 0.60 without using oyster shell was 24 MPa, while the specimen with 5% and 10% oyster shell grain increased to 23.89 MPa and 24.15 MPa, respectively, but the compressive strength of specimen with 15% oyster shell decreased again to 19 MPa.

Mokhtar et al. (2017) studied the behaviour of palm oil fibre block masonry prism under eccentric compressive loading. The authors reported that the compressive strength of the stabilized blocks was decreased as the fibre content was increasing. Their results were consistence with the study by Ismail (2009), they found that palm oil fibre that was used in the study enhanced the compressive strength at 7, 28 and 90 days respectively compared with the control mix, however, the strength did not increase linearly with an increase of fibre content. This situation was not shocking since the fibres themselves cannot resist axial compressive load that will lead not contribute to the compressive strength of blocks.

Sonar (2017) researched laterite soil cement composite blocks. He reported that the dry and wet compressive strength of soil cement blocks with 4% of cement varies from 5- 8.33 MPa and 0.99-3.14 MPa respectively. For blocks with 8% cement content, dry and wet compressive strength values vary from 8.10-9.86 MPa and 4.42-5.73 MPa respectively. Experimental investigation in the determination of various block characteristics concludes that optimum strength of soil cement block corresponds to clay content of 14 to 16% for both 4 and 8% cement blocks. It is observed from the results that the compressive strength of cement soil mortar decreases with the increase in the clay fraction of the mortar mix for a given cement content. It is a fact that bond formation is purely a mechanical phenomenon. It is also concluded that the optimum moisture content of block during construction is 75% to achieve maximum bond stress for blocks having cement content of 6-8%. The results show that cement soil mortar (with 15% cement) has 15-50% higher tensile bond strength as compared to cement mortar (1:6) and cement lime mortar (1:1:6).

Additionally, Kamat et al. (2021) also investigated the use of cow dung ash as a partial replacement for cement in mortar. The results of their study revealed that the compressive strength throughout the testing period of 7, 28 and 56 days with every replacement percentage gives a value higher than 3N/mm^2 as per 4031-6 (1988). The optimum percentage of replacement of cement with cow dung ash across 7, 28 and 56 days was found to be close to around 15% due to higher strength of around 10 N/mm^2 at 56 days of curing. As far as cost is concerned with the compressive strength and replacement of cement combined, the best percentage was found to be 25% cow dung ash. the replacement of cement with cow dung ash also reduces the workability of cement. the cow dung ash in mortar retards the setting time therefore it can be used as a retarder in mortar in hot weather conditions.

Adebakin et al., (2017) researched the uses of sawdust as an admixture in the production of lowcost and light-weight hollow sandcrete blocks. They reported in their study that at 28 days hydration period, only blocks made with 100% sand and 0% sawdust (4.26N/mm^2) met the required standard for sandcrete blocks (3.5 N/mm^2 - 10 N/mm^2). Few samples, at the 10% replacement, came closer to the standard and this could be taken as the optimum replacement level of sand with sawdust for the strength criterion. Their study also revealed that at the 28 days hydration period, the range of strength obtained was between 4.26 N/mm^2 (for 0% sawdust content) to 1.80 N/mm^2 (for 40% sawdust content). The result of their study indicated that the compressive strength decreases with increase in sawdust content for all ages at curing.

Olowu et al. (2014) studied Enhancing the Mechanical Properties of Lateritic Brick for Better Performance. They reported on compressive strength that compressive strengths of improved stabilized lateritic brick (ISLB) depend on the Zycosil Water Solution (ZWS) used for it production. At 28 days ISLB produced with ZWS of 1:100 have a compressive strength value of 3.16Nmm-2 while, ISLB produced with ZWS of 1:400 have a compressive strength value of 3.08Nmm-2. AULB have the least compressive strength value of 2.41Nmm-2 at 28 days.

2.6.2.2 Tensile strength

The tensile strength of a brick is the ability of the brick to resist fracture when the brick is being stretched. This has encouraged many researchers to study materials that can be used to enhance earth bricks to improve their tensile strength. An example is a study on the effect of sugarcane bagasse fibre on the strength properties of soil blocks by Danso et al. (2015). They reported that the tensile strength increased with an increase in the fibre content up to 0.5% and then decreased. It obtained an optimum fibre content as was in the case of the compressive strength test results. There was about 16% and 20% mean tensile strength increase of the reinforced blocks over the unreinforced at optimum respectively for red soil and brown soil. The ratio of tensile to compressive strength improvement was 59% and 105% respectively for red soil and brown soil, which is slightly lower than 133% reported by Danso et al. (2015). It was observed that the failure of unreinforced blocks was sudden and produced only one large crack, while the failure of the sugarcane bagasse fibre reinforced soil blocks was with multiple finer cracks. This means the failure was more gradual, acting more like a ductile than a brittle material.

Vodounon et al. (2019) reported on split tensile strength from a study that as the pineapple leaf fibre content increased up to 3% the tensile strength declined. The strength decreased because the high content of fibre in the blocks made a balling up which caused the blocks to lose strength. For both blocks stabilized with 3 and 5% of cement and reinforced with treated and untreated fibres, it was observed that the treated fibre had significantly improved the tensile strength when compared to those reinforced with untreated fibres. They also observed that with 3% of fibre content there was increase of 62.5% in strength for blocks reinforced with treated fibre over the untreated one, while with 5% of fibre content there was an increase of 66.7 in strength for blocks reinforced with treated fibre over the untreated one. The study also revealed that the unreinforced blocks divided into two pieces at the failure stage, while the fibre made the reinforced block to be more ductile and more flexible and this property made the reinforced blocks to be more resistant, also the tensile strength of the blocks increased when fibre content increased up to 3% but started decreasing afterwards. It was observed that the treated fibre had significantly increased the tensile strength of the blocks as compared with the untreated fibre.

Ige et al. (2022) reported on split tensile strength that all the stabilized adobe specimens attained increased tensile strength from 0% rice husk content to reach a peak strength at 0.75% rice husk content as recorded in the compressive strength test. The authors also reported that at 0.75% rice husk and lime content, the average tensile strengths of the adobe specimens were 0.65, 0.92, and 0.95 MPa, respectively, for RH 28-day sun-dried bricks, RH + L 7-day cured bricks, and RH + L 28-day cured bricks. Expectedly, the tensile strength declined at 1% rice husk content. A study by Danso (2020) with rice husk as stabilization in cement-based mortar attained similar results. This implies that the presence of rice husk in the adobe specimens helps to improve the tensile strength. Conversely, the tensile strength begins to decline after the peak. The study recorded about 132%, 170%, and 98% increases in tensile strength, respectively, for RH 28-day sun-dried bricks, RH + L 7-day cured bricks, and RH + L 28-day cured bricks between the 0% and 0.75% rice husk contents. Their findings also revealed that the percentage increase in tensile strength is more than that of the compressive strength. The increased tensile strength is attributed to the sliding restriction of the rice husks in the soil matrix and the rice husks' possession of better tensile characteristics than the soil matrix as well as uniform distribution and orientation of the rice husks in the soil matrix. The tensile strength decreased after the peak due to a reduced bond between the rice husk and the soil because of increased quantities of the rice husks that crossed each other. They observed that the 1% rice husk content attained better tensile strength than the control by about 104%, 167%, and 95%, respectively, for RH 28-day sun-dried bricks, RH + L 7-day cured bricks, and RH + L 28-day cured bricks. The authors further observed trends of the tensile strength results that the RH + L 28-day cured bricks obtained the highest, and the lowest was attained by the RH 28-day sun-dried bricks. This implies that the addition of lime and the rice husk to stabilized adobe specimens improved the tensile strength.

Danso (2017) reported on split tensile strength that the specimens with pidiproof liquid waste chemical increase with increased curing age. He also reported that the average splitting tensile strength of all the stabilised compressed earth blocks was about two times that of the unstabilised blocks. The author also observed that the higher liquid chemical content (1.5%) achieved the higher strength as was also observed in the compressive strength test. Experimental Hanuseac et al. (2021) studied hollow blocks with fly ash waste, plastic waste and wood waste. They reported that the value of split tensile strength was influenced by the type and dosage of waste. The waste type chopped PET as a replacement for sort 0–4 mm in a dosage of 20% resulted in an increase in the strength. The waste type wood waste as a replacement for sort 0–4 mm in a dosage of 40% resulted in a decrease in the strength. The dispersed polyester fibers increased the split tensile strength in comparison with the control mix by 12.8%. The mechanical strengths of concretes with different waste types as replacements for aggregates were lower than those of the control mix. In the case of concrete with fly ash and polyester fibres, the compressive strength was lower than that of the control mix, but the flexural strength and split tensile strength were highest.

2.6.3 Abrasion

Abrasion is the ability of the brick to withstand wearing or any external rubbing such as rain or wind. This has motivated many researchers to look for fibre and shells to enhance the properties of bricks to withstand wear. An example can be seen in a study by Adogla et al. (2016). The study by Adogla et al. (2016) reported that the abrasion resistance of the bricks when the test specimens were subjected to abrasion by brushing for 60 uniformly cycles using a wire brush. Higher abrasion resistance coefficients indicated higher bond strength between particles whereas specimens exhibiting lower coefficients showed weaker bonds. Data derived from the study showed that bricks with 30% eggshells exhibited higher resistance to abrasion (wear) whiles the control batch (without eggshells) showed the least resistance to wear.

The study by Yalley and Manu (2013) also revealed the relationship between the abrasive resistance coefficient and the cow dung content that the abrasive resistance increased with increase in the cow dung content up 20%. As defined, a high abrasive coefficient shows a large brushing area is required to yield a certain amount of discarded material, i.e., the higher the abrasion coefficient the lesser the discarded materials. This then implied that the cow dung in the brick helped to reduce the wear of the bricks from external factors. However, abrasive resistance again started decreasing when the cow dung content was beyond 20%. This is expected because the bricks with 20% cow dung content have the highest density, and thus resulting in the best resistance to abrasion from rainwater and from any form of rubbing against the bricks.

Additionally, the study by Danso et al. (2013) indicated that there was a rapid reduction in the wearing of the blocks up to 0.5 wt. % fibre content. Likewise, a study by Yalley and Manu (2013) recorded increase in abrasion (wearing) with cow dung increase up to 20 % after which the wearing rate levels off or reversed slightly with further fibre inclusion. The greatest reduction in wearing as compared to unreinforced soil blocks was 20%, 38% and 33%, respectively for oil palm, coconut and bagasse fibres reinforced soil blocks for soil R. While the reduction for soil B was 47%, 50% and 47%, respectively for oil palm, coconut and bagasse fibres reinforced soil blocks. This implies that the inclusion of fibres in the soil blocks will increase the resistance of the blocks against wearing caused by external factors such as wind and human/animal activities. It should be noted that reduction in wearing after the optimum of 0.5 wt. % fibre content has a comparatively small effect, allowing blocks to be made with a reasonable range of fibre contents without significant deviation from optimum wearing resistance. Similarly, a study with cement as stabilizer by Yalley and Manu (2013) recorded increase in abrasion (wearing) with cement increase up to 4 wt. %, after which there was no increase with further addition of cement content.

Vodounon et al. (2019) also reported on abrasion test that as the abrasion resistance increased with an increase in fibre content up to 3% and afterward it decreased. In addition, it was observed that the blocks stabilized with 5% cement resisted abrasion more than those reinforced with 3% of cement. Furthermore, the blocks reinforced with treated fibres had higher abrasion resistance as compared to non-treated ones.

Zievie and Yalley and Manu (2016) also revealed that the abrasion coefficient for bricks without ALBWW content was 6.45cm2/g. This increased steadily to 9.45cm2/g for bricks stabilized with 100% ALBWW. A high abrasion coefficient shows that a large brushing area is required to yield a certain amount of discarded material. This then implies that the increase in the ALBWW contents increased the brick's resistance to wear and tear by cutting and erosive agents such as wind, rain, snow, etc. These findings are similar to those of Walker, 1997 and Morton, 2008 who observed that agro-based juicy liquid waste stabilizers increase compacted/compressed soil weight thereby improving its abrasion resistance.

Based on the results of the study by Zievie and Yalley and Manu (2016), the addition of the African locust bean wastewater in the soil bricks has steadily improved its abrasion resistance. Even though the maximum values were achieved at the 100% ALBWW content, the results obtained at the 25% and 50 % ALBWW content met the required recommendations for earth housing. They also reported that ALBWW which is an environmental nuisance can be used to replace potable water and also as a stabilizer for masonry units in construction. Finally, their study recommended that to produce cheap and environmentally friendly stabilized soil specifically for rammed, cob, wattle, and daub walling, the soil type, and its suitability must be established before using ALWW as mixing water.

Senewu et al. (2018) reported on abrasion resistance that as the cow dung content increased the abrasion resistance decreased. The high concentration of fibres has been found by Ismail and Yaacob (2011) to cause them to bunch together and lose cohesion with the soil leading to the breaking up of the soil matrix. This can cause weakening of the soil mixture thus increasing in abraded material. Their results indicate that increase of lime in clay soil having 5% cement leads to a decrease of abraded material. The authors also reported that the reaction of cement and water liberates calcium hydroxide which reacts with clay to form a pozzolanic binder. However, if the clay content is too high the free lime from cement hydration will not be sufficient to sustain the reaction. Therefore, the addition of hydrated lime aided the pozzolanic reaction in forming insoluble colloidal gels which led to increased resistance to abrasion. Generally, abrasion resistance of clay soil blocks is well achieved with the addition of lime rather than RHA to cement.

Olowu et al. (2014) the authors reported on abrasion resistance that improved stabilized lateritic brick (ISLB) offers resistance to abrasive forces relative to the concentration of the Zycosil Water Solution (ZWS) used in its production; that is, the higher the concentration of ZWS the higher the resistance offered by the brick against abrasive forces. ISLB produced with ZWS of 1:100 have an abrasion value of 1%, CSLB has an abrasion value of 3% and AULB has an abrasion value of 12%. (CSLB) was next in rank, and on the durability, the scale was rated firm and Adobe Unstabilized Lateritic Brick (AULB) was rated loose on the durability scale.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

Materials used for the study were earth, palm fruit fibres (PFF), cow dung (CD), and water.

3.1.1 Earth

Figure 3.1 shows the earth used for the study. The earth was obtained from Hemang -Buoho in the Ashanti region of Ghana. The earth was extracted below ground level at 150mm depth to avoid the inclusion of organic materials.

Figure 3.1: Earth

3.1.2 Cow dung

The cow dung (CD) was collected from the Kumasi abattoir in wet form as shown in Figure 3.2a. The wet cow dung was dried for 14 days until uniform dryness of the CD was attained. Finally, the dried CD was crashed to obtain finer particle size as shown in figure 3.2b.

Figure 3.2a (Wet cow Dung)

Figure 3.2b (Dried and crushed cow Dung)

3.1.3 Palm fruit fibres

The Palm fruit fibres were collected in a wet form from Offinso oil Mill Limited in the Ashanti Region of Ghana. The fibres were soaked in hot water for 5 minutes to remove the oil content which could influence the properties of the bricks, as presented in Figure 3.3a. The palm fruit fibres were dried for 14 days to ensure uniform dryness, as shown in Figure 3.3b.

Figure 3.3a (Removing of oil from PFF)

(Figure 3.3b: Dried PFF)

3.1.4 Water

Water for mixing the materials conformed to BS EN 1008 (2002).

3.2 Methods

This section comprises methods or procedures for determining the particle size distribution of earth and cow dung, fibre aspect ratio of palm fruit fibres, sampling details, batching of materials, mixing of materials, moulding, and curing.

3.2.1 Particle size distribution of earth

A standard set of sieves were used for particle size distribution which conformed to BS EN 1377-1-1990. The soil sample was oven dried for 1 hour to ensure uniform dryness. One kilogram of dried soil was weighed and recorded. The sieves for the study were carefully cleaned before the test commenced. The sieves were arranged in descending order from 14mm, 10mm, 6.3mm, 5mm, 3.35mm, 2.36mm, 2.00mm, 1.18mm, 0.60mm, 0.30mm, 0.212mm, 0.150mm, 0.075mm, 0.063mm, up to the pan respectively. The soil sample was poured into the top sieve and placed a cover/cap over it. The sieves were placed in a mechanical shaker and shaken for 10 minutes. The mass of soil retained on each sieve was recorded.

3.2.2 Particle size distribution of cow dung

The particle size distribution of cow dung was conducted using BS 1377-1-1990 as a guide. The cow dung sample was oven dried for 1 hour to ensure uniform dryness. 0.5kg. of the dried cow dung was weighed and recorded. The sieves for the study were carefully cleaned before the test commenced. The sieves were arranged in descending order from 5mm, 3.35mm, 2.36mm, 2.00mm, 1.18mm, 0.60mm, 0.30mm, 0.212mm, 0.150mm, 0.075mm, 0.063mm, up to the pan. The cow dung sample was poured into the top sieve and placed a cover/cap over it. The sieves were placed in a mechanical shaker and shaken for 10 minutes. The mass of soil retained on each sieve was recorded.

3.2.3 Fibre aspect ratio of palm fruit fibres

Fifty fibres were picked randomly to determine the length and diameter of the fibres (Danso et al.,2015). The palm fruit fibre was straightened and its length was measured and recorded by the use of a steel rule. The diameter of the fibre at three different positions was measured and recorded by the use of a digital calliper as shown in figure 3.4. The average diameter and average length were calculated and recorded, then the fibre aspect ratio was finally determined using the formula below:

$$FAR = \frac{L}{D}$$

Where

FAR = Fibre aspect ratio

L = length of the fibre (mm).
D = diameter of the fibre (mm).

Figure 3.4: Measuring the diameter of the fibre

3.2.4. Preparation of specimens

The number of specimens used for the study was determined using BS EN 772-1(2011) as a guide as shown in Table 3.1.

Table 3.1: Sampling details

Percentage replacement CD Content	Percentage Addition PFF Content	Compressive Strength 28 days	Water Absorption 28 days	Density 28 days	Abrasion 28 days	Tensile Strength 28 days	Sub-Total
0%	0%	5	5	5	5	5	25
2%	0.1%	5	5	5	5	5	25
4%	0.2%	5	5	5	5	5	25
6%	0.3%	5	5	5	5	5	25

8%	**0.4%**	**5**	**5**	**5**	**5**	**5**	**25**
10%	**0.5%**	**5**	**5**	**5**	**5**	**5**	**25**
Total							**150**

3.2.5 Batching of materials

Tables 3.2 and 3.3 summarize the quantities of materials used for the study. The materials were batched by weight. An average compressed earth brick of 3.00kg was used to determine the weight of materials used for the study. The earth content was replaced with cow dung content ranging from 0%, 2%, 4%, 6%, 8% and 10% respectively while palm fruit fibre content of 0%,0.1%, 0.2%, 0.3%, 0.4% and 0.5% was added to the mixture respectively.

Table 3.2: Batching details per mould

CD Replacement Content	**CD (kg)**	**EARTH (kg)**	**PFF Addition Content**	**PFF (kg)**	**Water (kg)**
0%	0	3.00	0%	0	0.47
2%	0.06	2.44	0.1%	0.003	0.47
4%	0.12	2.32	0.2%	0.006	0.47
6%	0.18	2.14	0.3%	0.009	0.47
8%	0.24	1.90	0.4%	0.012	0.47
10%	0.30	1.60	0.5%	0.015	0.47
Total	**0.9**	**12.81**		**0.045**	**2.82**

Table 3.3: Batching details for moulding 25 bricks

CD Replacement Content	**CD (kg)**	**EARTH (kg)**	**PFF Addition Content**	**PFF (kg)**	**Water (kg)**
0%	0	62.5	0%	0	11.75
2%	1.5	61.00	0.1%	0.075	11.75
4%	3.00	58.00	0.2%	0.15	11.75
6%	4.5	53.50	0.3%	0.225	11.75

8%	6.00	47.50	0.4%	0.30	11.75
10%	7.5	40	0.5%	0.375	11.75
Total	**22.50**	**322.50**		**1.125**	**70.5**

3.2.6 Mixing

The materials for the study were mixed manually, the measured earth was spread on a flat surface. The cow dung content was then added to the earth followed by palm fruit fibres content respectively as shown in Figure 3.5a and 3.5b respectively. The materials were then mixed until a uniform mixture was attained. Measured water was finally added and mixed thoroughly until a uniform mixture was attained.

Figure. 3.5a (adding of CD content)

Figure. 3.5a (adding of PFF content)

3.2.7 Moulding

Moulding of the specimen was done mechanically by a compressed hydraulic brick moulding machine of mould size 100mm X 100mm X 130mm. To ensure easy removal and smooth finish of the earth bricks, the mould was oiled. The mixture was placed in the mould in three layers and compacted 25 times using a wooden rammer to fill the mould as shown in figure 3.6a. A metal float was then used to level the surface of the mould to remove excess mixture as shown in figure.3.6b, the top cover of the mould was then placed and tightened firmly, a pressure of 140 bars was applied from the hydraulic jack of the machine to ensure that the mixer was uniformly compressed in the mould to obtain the desired compressed earth bricks.

Figure 3.6a (Tamping of moulds)

Figure 3.6b (Levelling the surface of the moulds)

3.2.8 Curing

The specimens were cured using the air-drying method as shown in figure 3.7 for 28 days.

Figure 3.7 air-drying of the specimen

3.3 Testing procedures

The specimens were tested for water absorption, density, abrasion, Compressive strength, and tensile strength respectively after 28 curing days.

3.3.1 Density

The density of the specimen was determined using BS EN 771-1(2003) as a guide. Specimens were tested for density after 28 curing days. The specimen was weighed and their masses were recorded. The average volume of the specimen was recorded. Then the density in Kg/m^3 of the specimen was calculated using the formula in equation 3.1;

$$D = \frac{M}{V} \text{ ----------------- Equation 3.1}$$

Where:

D= density in **(**Kg/m^3**)**
M= mass of the specimen in (kg)
V= volume of specimen in (m^3)

3.3.2 Water absorption

The objective of this test was to determine the percentage of water absorbed by the specimen. The test was conducted using BS EN 772-11(2011) as a guide. Specimen of 28 curing days was tested for water absorption in percentage. The bricks specimens were oven-dried at a temperature of 110^0C for 24 hours. The specimen was then allowed to cool down at normal room temperature and the oven-dried weight of the specimen was recorded as (Md). The specimen was soaked in 5mm depth clean water for 10 minutes as used by Zievie and Yalley (2016). Bricks were then removed after 10 min. and wiped off their surface water and their final mass was recorded as (Ms). Water absorption in the percentage of the specimen was calculated using the formula in equation 3.2;

$$Ws \quad = \frac{Ms - \ Md}{Md} x100\% \quad \text{----------------- Equation 3.2.}$$

Where,

Ws = Water absorption of the specimen (%).

Md = Mass of the specimen after oven drying (Kg).

Ms = mass of the specimen after soaking (Kg).

3.3.3 Compressive strength

The specimens were tested for Compressive strength after 28 curing days using BS EN 772-1(2011) as a guide. A computerized universal testing machine of maximum capacity of 1000 KN was used to conduct the compressive strength as seen in figure 3.7. The testing machine was used to apply load on the brick specimen at a constant rate of 0.05 N/mm^2/s until the specimen fractured, the applied load at which the brick failed was recorded (N). Then the cross-sectional area of the brick was calculated and recorded (m^2). The maximum compressive strength was calculated using equation 3.3;

$$F \quad = \frac{P}{A} \text{------------------------------------ Equation 3.3}$$

Where

F=Compressive strength of the brick in (N/mm^2)

P= Maximum Load applied to the brick in (N)

A= cross-sectional area of the specimen (mm^2)

Figure 3.7: Computerized universal testing machine

3.3.4 Split tensile strength

The split tensile strength test was conducted using BS EN 12390-6(2009) as a guide. After 28 curing days, the specimens were tested for split tensile strength. The load was applied continuously at a constant rate of 0.05N/mm^2 /s until the specimen failed, and the maximum load was recorded. To avoid compound stress effects accuracy centring of the specimen within the loading plate of the testing machine was done as seen in figure 3.9. The tensile strength was calculated using the formula in equation 3.4;

$$T = \frac{2P}{\pi WL} \text{------------------------------------ Equation 3.4.}$$

Where,

T =Tensile strength (N/mm^2)

P = Maximum applied load (N)

L= length of the specimen in (mm)

B= Width of the specimen in (mm)

Figure 3.8: Centring of loading plate of the machine within the specimen.

3.3.5 Abrasion resistance

After 28 curing days, the specimens were tested for abrasion resistance using the surface wire brushing method as used by Zievie and Yalley (2016). The test was conducted to determine the surface hardness of the specimen and its ability to withstand wear. The specimen was weighed and its mass was recorded as (M1), placed on top of a table, and secured against sliding. The top surface of the specimen which would be used as facing was given 60 strokes of wire brush in forward and backward motions per second as seen in figure 3.9, after which the specimen was reweighed and recorded. Much care was taken so that the brush width did not exceed the width of the specimen more 2mm. After the brushing of the specimen all the loose substances were clean off from the specimen with a soft brush and reweighed and recorded as (M2) and the abrasion resistance of specimens was then calculated in percentage using the formula equation 3.5:

$$Ca = \frac{A}{M1 - M2} X\ 100$$ --Equation 3.5.

Where,

Ca = Abrasion coefficient in percentage

A = Area of the brushed surface

M1= mass of brick before brushing

M2 = mass of brick after brushing.

Figure 3.9: Brushing of the specimens

3.3.6 Data analysis and presentations

Data obtained from the study were analysed using Microsoft excel v.15. Tables and charts were used to present the data using descriptive and inferential statistics. One way ANOVA analysis was conducted to determine whether there were statistically significant differences between the test results. Furthermore, correlation and regression analyses were also conducted to determine the relationship between the test results.

CHAPTER FOUR

RESULTS

4.0 Introduction

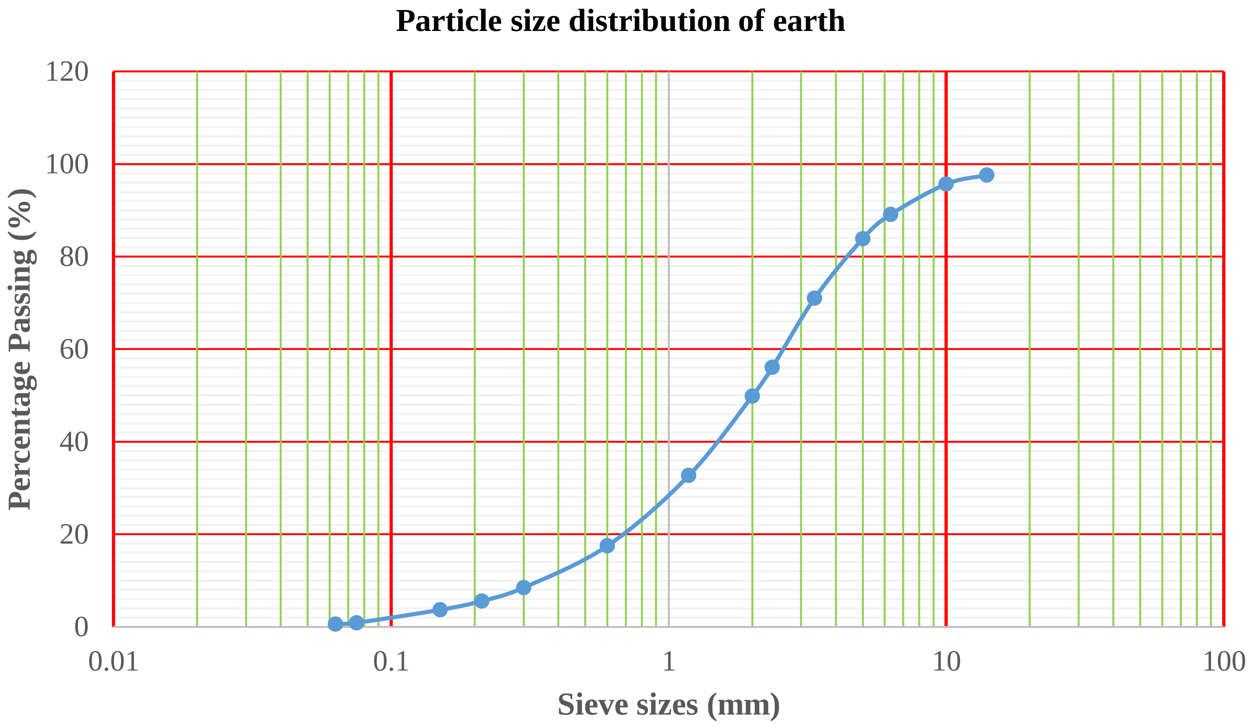
This chapter presents the results of the study.

4.1 Results of the particle size distribution of earth

Table 4.1 shows the particle size distribution table and figure 4.1 shows the particle size distribution curve of the earth used for the study.

Table 4.1: Particle size distribution of earth

Sieve Sizes mm	Mass Retained (kg)	Percentage (%) Retained	Cumulative Percentage (%) Retained	Percentage (%) Passing
14	0.024	2.4	2.4	97.6
10	0.019	1.9	4.3	95.7
6.3	0.066	6.6	10.9	89.1
5	0.052	5.2	16.1	83.9
3.35	0.129	12.9	29	71
2.36	0.149	14.9	43.9	56.1
2	0.062	6.2	50.1	49.9
1.18	0.172	17.2	67.3	32.7
0.600	0.152	15.2	82.5	17.5
0.300	0.09	9	91.5	8.5
0.212	0.029	2.9	94.4	5.6
0.150	0.019	1.9	96.3	3.7
0.075	0.028	2.8	99.1	0.9
0.063	0.003	0.3	99.4	0.6
pan	0.006	0.6	100	0



Below	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse
0.002 mm	0.002-0.006 mm	0.006-0.02 mm	0.02-0.06 mm	0.06-0.2 mm	0.2-0.6 mm	0.6-2 mm	2-6 mm	6-20 mm	20-60 mm
Clay =0%	**Silt =0%**			**Sand =49.9%**			**Gravel =50.1%**		

Figure 4.1 Particle size distribution of earth

4.2 Results of the particle size distribution of cow dung

Table 4.2 shows the particle size distribution table and figure 4.2 shows the particle size distribution curve of the cow dung used for the study.

Table 4.2: Particle size distribution of cow dung

Sieve Sizes mm	Mass Retained (kg)	Percentage (%) Retained	Cumulative Percentage (%) Retained	Percentage (%) Passing
5	0.006	1.2	1.2	98.8
3.35	0.106	21.2	22.4	77.6
2.36	0.093	18.6	41	59
2	0.083	16.6	57.6	42.4
1.18	0.062	12.4	70	30
0.6	0.054	10.8	80.8	19.2
0.3	0.025	5	85.8	14.2
0.212	0.024	4.8	90.6	9.4
0.15	0.019	3.8	94.4	5.6
0.075	0.02	4	98.4	1.6
0.063	0.001	0.2	98.6	1.4
pan	0.001	0.2	100	0

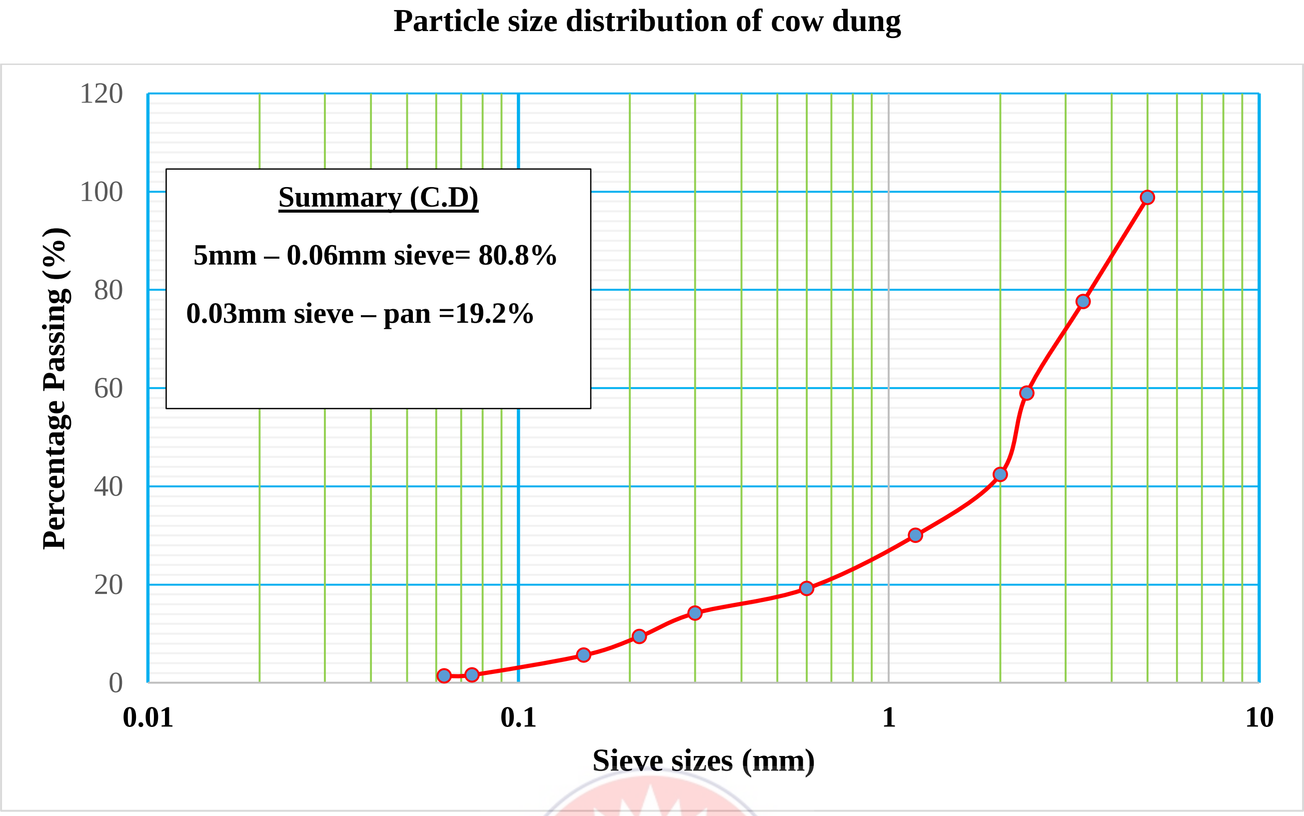


Figure 4.2 Particle size distribution of cow dung

4.3 Results of the fibre aspect ratio of pam fruit fibres

Table 4.3 shows the results of the fibre aspect ratio of palm fruit fibres used for the study.

Table 4.3 fibre aspect ratio of palm fruit fibres

Property	**Value**
Fibre form	Single
Average length (mm)	8.3
Average diameter (mm)	0.35
Aspect ratio	166:7

4.4 Results of Density test

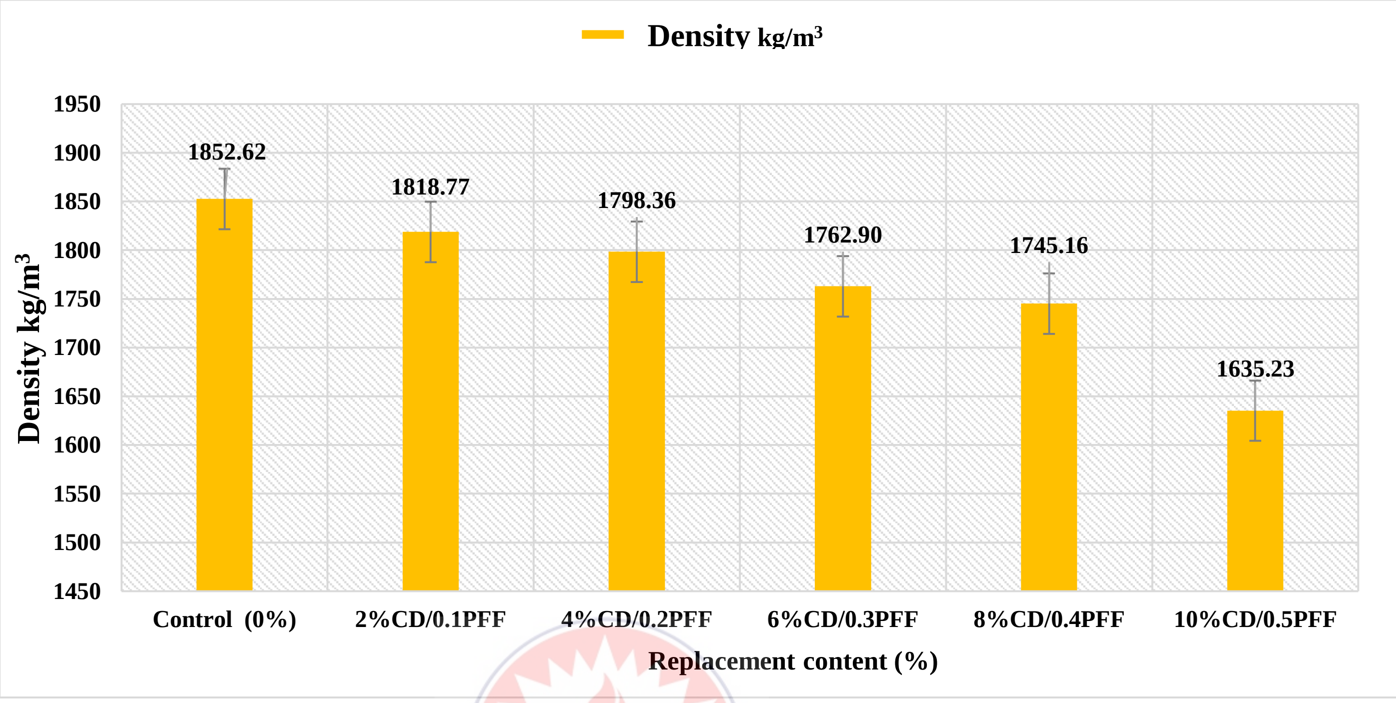


Figure 4.3: Density Test results

4.5 Results of Water Absorption

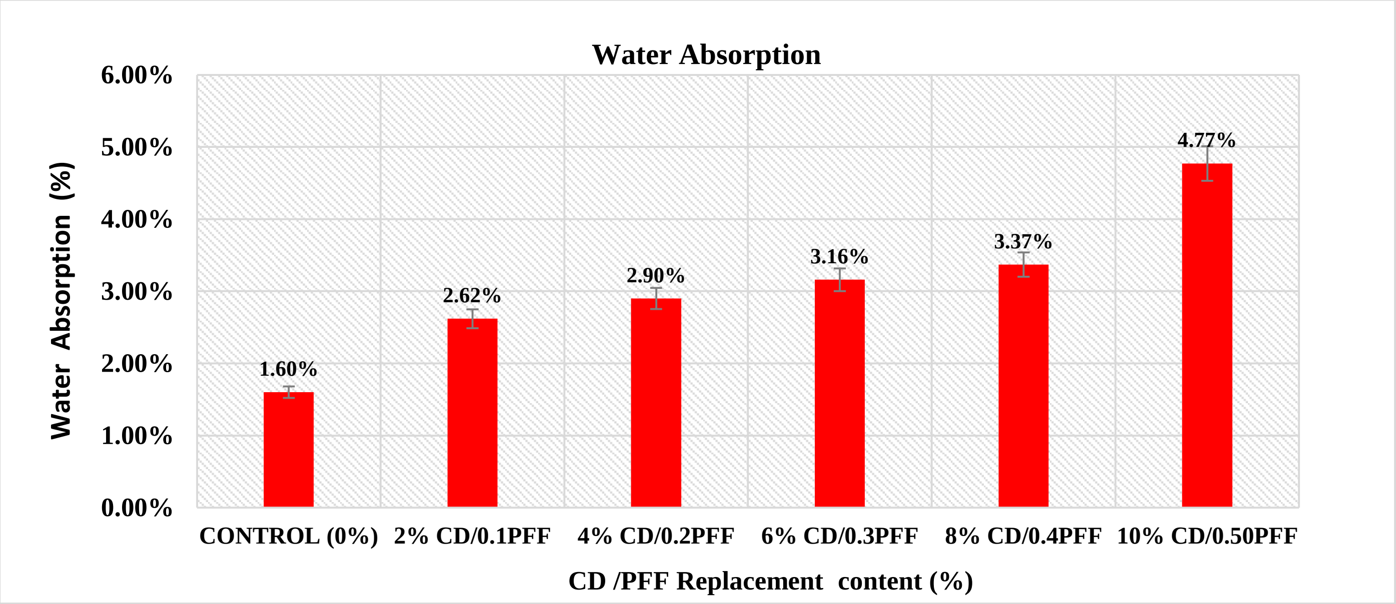


Figure 4.4: Water Absorption Test results

4.6 Results of compressive strength

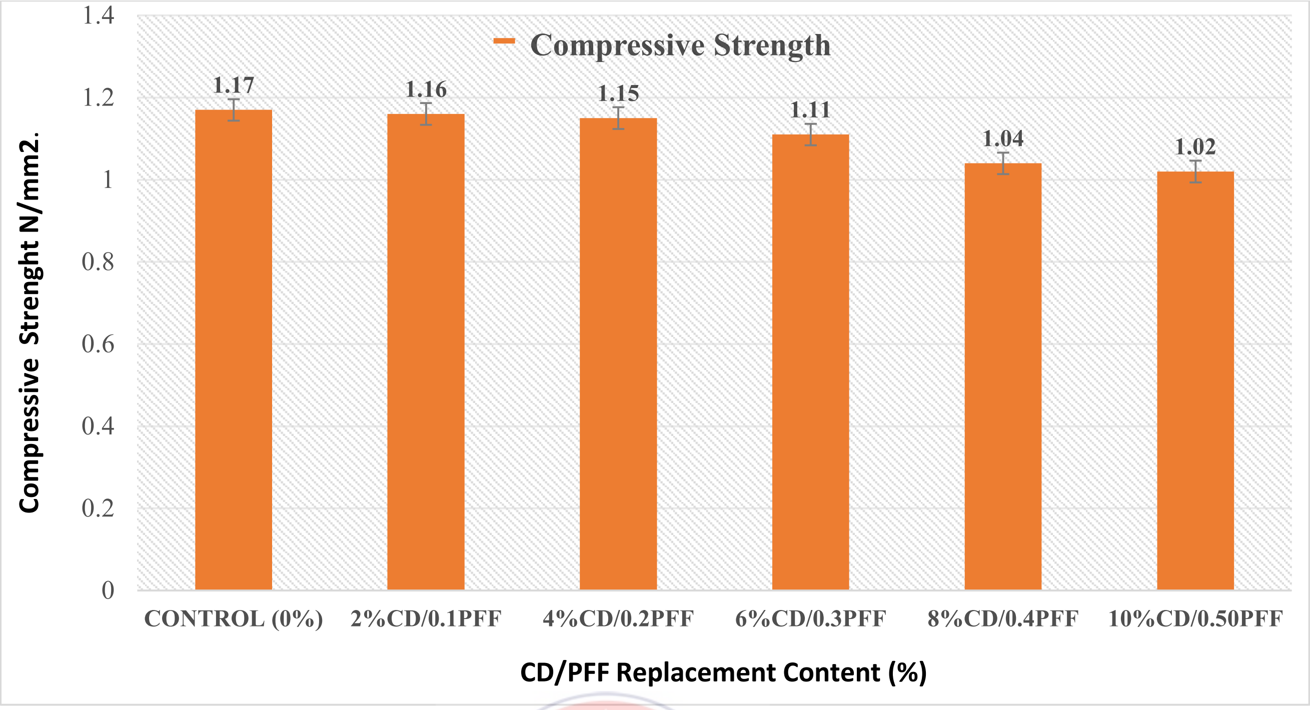


Figure 4.5: Compressive strength test results

4.7 Results of one-way -ANOVA analysis of the compressive strength.

Table 4.4 shows one –way- ANOVA analysis and multiple comparisons of the compressive strength of the specimens.

Table 4.4 One–way- ANOVA analysis and multiple comparisons of the compressive strength

Treatment Name	N	Missing	Mean	Std Dev	SEM
Control	5	0	1.173	0.140	0.0624
2% CD/0.1 PFF	5	0	1.159	0.0303	0.0135
4% CD/0.2 PFF	5	0	1.150	0.162	0.0723
6% CD/ 0.3PFF	5	0	1.106	0.140	0.0624
8% CD/0.4PFF	5	0	1.035	0.109	0.0489
10% CD/0.5PFF	5	0	1.018	0.130	0.0583

All Pairwise Multiple Comparison Procedures (Holm-Sidak method)

Comparison	Diff of Means	t	P	P<0.05
0% vs. 10 CD/0.5PFF%	0.155	1.983	0.613	Not significant
2% CD/0.1PFF vs. 10 CD/0.5PFF	0.141	1.804	0.718	Not significant
0% vs. 8%CD/0.4PFF	0.138	1.765	0.718	Not significant
4% CD/0.2PFFvs. 10CD/0.5PF	0.131	1.686	0.744	Not significant
2% CD/0.1PFF vs. 8%CD/0.4PFF	0.124	1.586	0.780	Not significant
4% CD/0.2PFF vs. 8CD/0.4PFF	0.114	1.467	0.820	Not significant
6%CD/0.3PFF vs. 10% CD/0.5PFF	0.0878	1.126	0.944	Not significant
6% CD/0.3PFF vs. 8%CD/0.4PFF	0.0708	0.908	0.977	Not significant
Control vs. 6% CD/0.3PFF	0.0668	0.857	0.973	Not significant
2% CD/0.1PFFvs. 6% CD/0.3PFF	0.0528	0.677	0.985	Not significant
4% CD/0.2PFFvs. 6% CD/0.3PFF	0.0436	0.559	0.987	Not significant
Control vs. 4% CD/0.2 PFF	0.0232	0.298	0.997	Not significant
8% CD/0.4PFFvs. 10% CD/0.5PFF	0.0170	0.218	0.995	Not significant
Control vs. 2%CD/0.1 PFF	0.0140	0.180	0.980	Not significant
2% CD/0.1PFF vs. 4% CD/0.2PFF	0.00920	0.118	0.907	Not significant

4.8 Results of tensile strength test

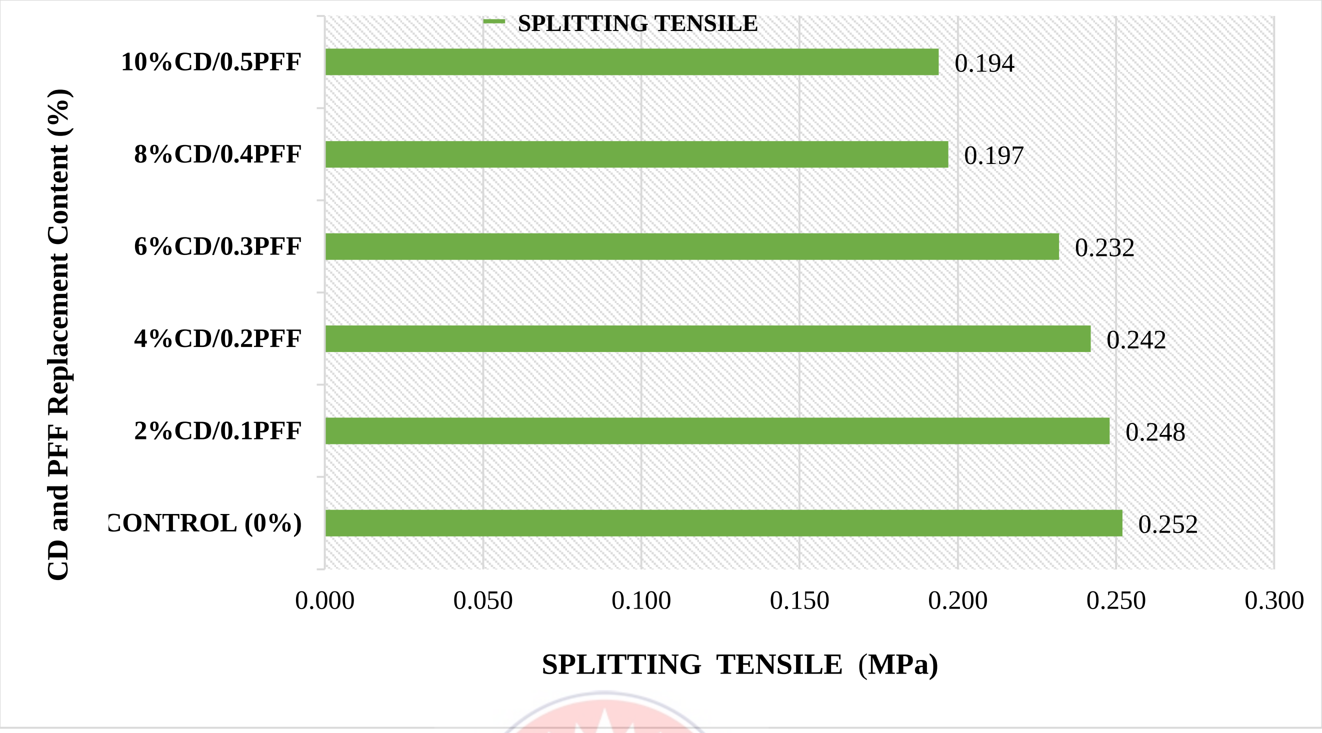


Figure 4.6: Split tensile strength test results

4.9 Results of one–way- ANOVA analysis of the tensile strength.

Table 4.5 shows one –way- ANOVA analysis and multiple comparisons of the split tensile strength of the specimens.

Table 4. 5 One–way- ANOVA analysis and multiple comparisons of the tensile strength.

Group	N	Missing	Median	25%	75%
Control (%)	5	0	0.249	0.0185	0.00826
2%CD/0.1PFF	5	0	0.248	0.0382	0.0171
4%CD/0.2PFF	5	0	0.242	0.0755	0.0338
6%CD/0.3PFF	5	0	0.232	0.0282	0.0126
8%CD/0.4PFF	5	0	0.198	0.0262	0.0117
10%CD/0.5PFF	5	0	0.194	0.0105	0.00472

All Pairwise Multiple Comparison Procedures (Tukey Test).

Comparison	Diff of Means	t	P	P<0.05
0% vs. 10 CD/0.5PFF%	0.0546	2.196	0.459	not significant
2% CD/0.1PFF vs. 10 CD/0.5PFF%	0.0532	2.139	0.475	not significant
0% vs. 8%CD/0.4PFF	0.0506	2.035	0.523	not significant
2% CD/0.1PFF vs. 8%CD/0.4PFF	0.0492	1.978	0.535	not significant
4% CD/0.2PFFvs. 10CD/0.5PF	0.0474	1.906	0.556	not significant
4% CD/0.2PFF vs. 8CD/0.4PFF	0.0434	1.745	0.637	not significant
6%CD/0.3PFF vs. 10% CD/0.5PFF	0.0374	1.504	0.764	not significant
6% CD/0.3PFF vs. 8%CD/0.4PFF	0.0334	1.343	0.822	not significant
Control vs. 6% CD/0.3PFF	0.0172	0.692	0.992	not significant
2% CD/0.1PFFvs. 6% CD/0.3PFF	0.0158	0.635	0.990	not significant
4% CD/0.2PFFvs. 6% CD/0.3PFF	0.01000	0.402	0.997	not significant
0% vs. 4% CD/0.2 PFF	0.00720	0.290	0.997	not significant
2% CD/0.1PFF vs. 4% CD/0.2PFF	0.00580	0.233	0.994	not significant
8% CD/0.4PFFvs. 10% CD/0.5PFF	0.00400	0.161	0.984	not significant
0% vs. 2%CD/0.1 PFF	0.00140	0.0563	0.956	not significant

4.10 Results of Abrasion resistance test

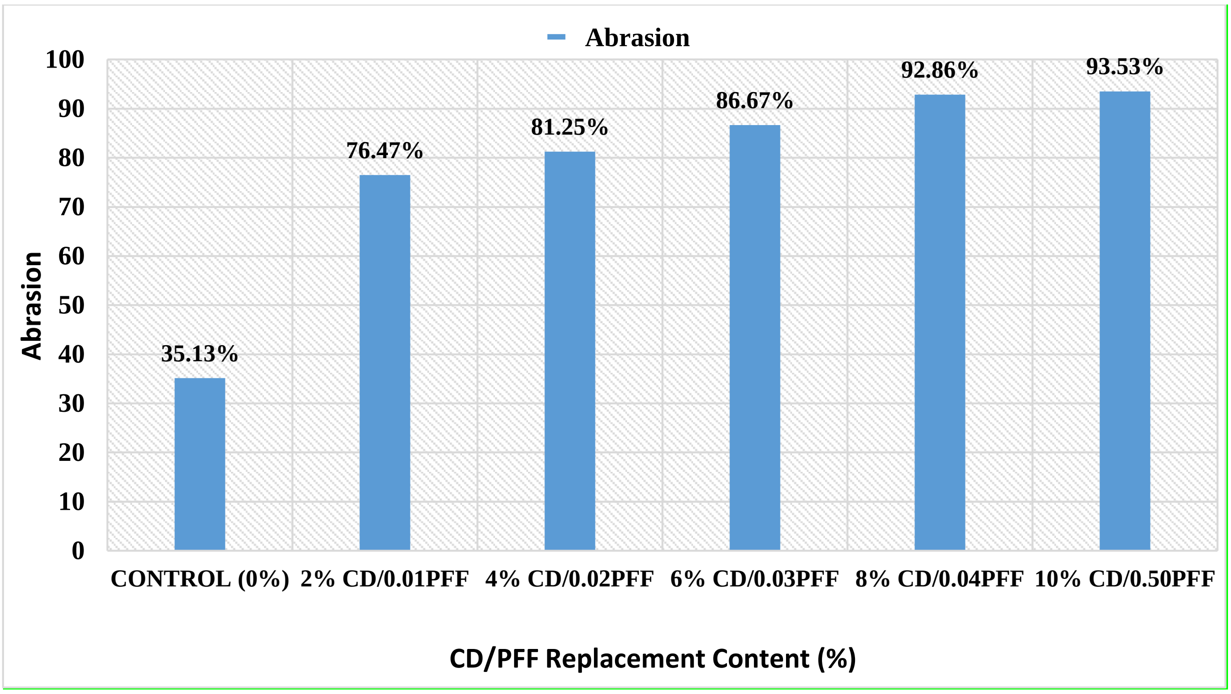


Figure 4.8: Abrasion resistance test results.

4.11 Correlation between the construct

Table 4.6 summarises the correlation between the CD/PFF content and Density, water absorption, abrasion resistance, compressive and split tensile strength.

Table 4.6 Correlation between the construct

		CD&PFF Content	Density (Kg/m^3)	Compressive (N/mm^2)	Tensile (MPa)	Water (%)	Abrasion (%)
CD&PFF Content	Pearson Correlation	1	-.930	-.903	-.971	.903	-.981
	Sig. (2-tailed)		.022	.006	.013	.035	.003
	N		5	5	5	5	5
Density (Kg/m^3)	Pearson Correlation		1	.892	.856	-.996	.843
	Sig. (2-tailed)			.042	.064	.000	.073
	N			5	5	5	5
Compressive (N/mm^2)	Pearson Correlation			1	.994	-.862	.969
	Sig. (2-tailed)				.001	.060	.007
	N				5	5	5
Tensile (MPa)	Pearson Correlation				1	-.827	.959
	Sig. (2-tailed)					.084	.010
	N					5	5
Water Absorption (%)	Pearson Correlation					1	-.804
	Sig. (2-tailed)						.101
	N						5
Abrasion resistance	Pearson Correlation						1
	Sig. (2-tailed)						
	N						

‘$P < 0.05$ and “$P < 0.01$.

4.12 Relationship between density and water absorption of reinforced earth bricks

Figure 4.9 shows the relationship between density and water absorption of compressed earth bricks reinforced with cow dung and palm fruit fibres.

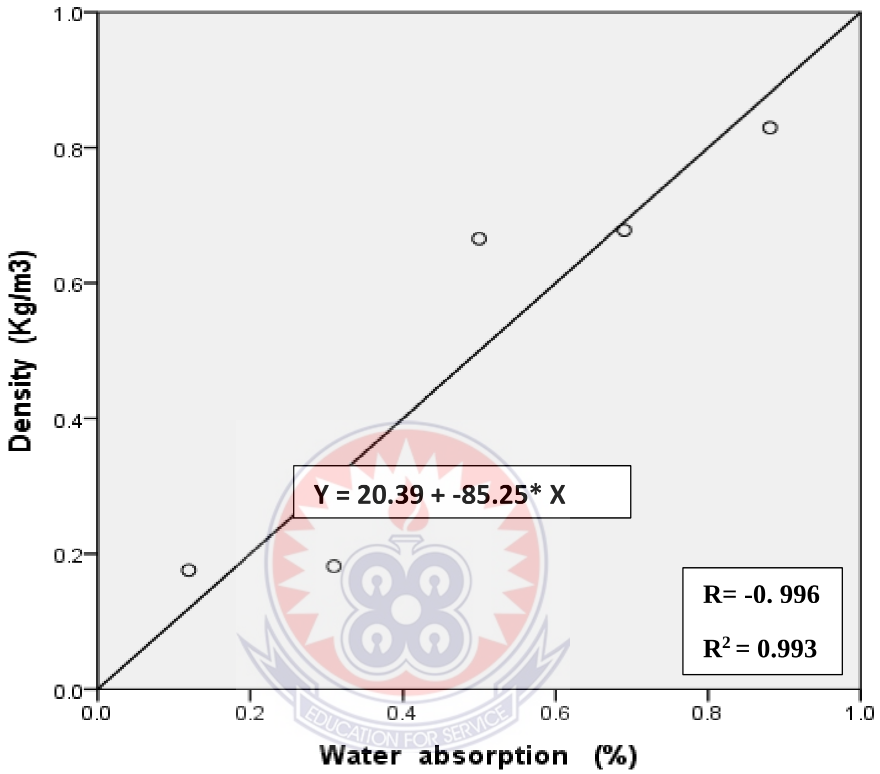


Fig 4.9: Relationship between Density and Water Absorption

4.13 Relationship between compressive strength and split tensile strength of reinforced earth bricks

Figure 4.10 presents the relationship between compressive strength and split tensile strength of the compressed earth bricks reinforced with cow dung and palm fruit fibres.

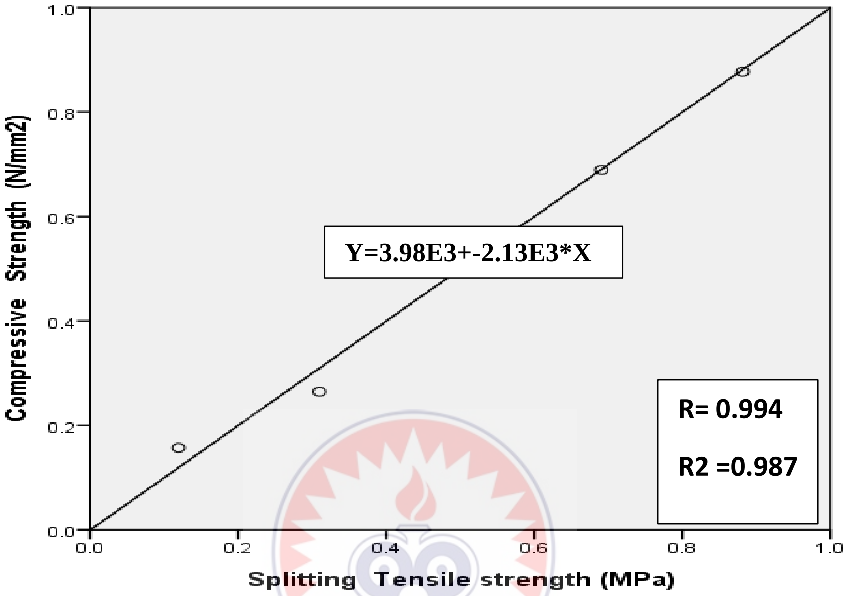


Fig 4.10: Relationship between compressive strength and split tensile strength

4.14 Relationship between compressive strength and density of reinforced earth bricks

Figure 4.11 shows the relationship between compressive strength and density of the compressed earth bricks reinforced with CD and PFF.

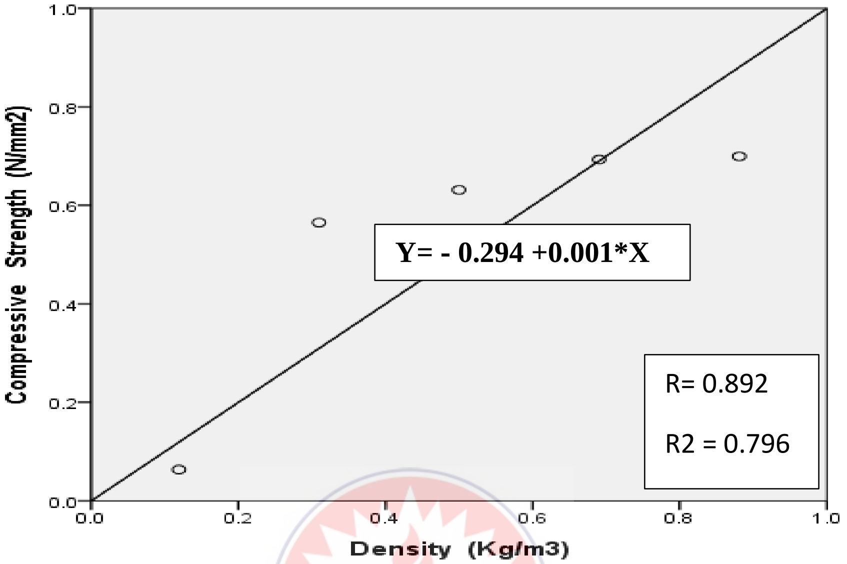


Fig 4.11: Relationship between Compressive strength and Density

4.15 Relationship between the compressive strength and abrasion resistance of reinforced earth bricks

Figure 4.12 shows the relationship between the abrasion resistance and compressive strength of compressed earth bricks reinforced with CD and PFF.

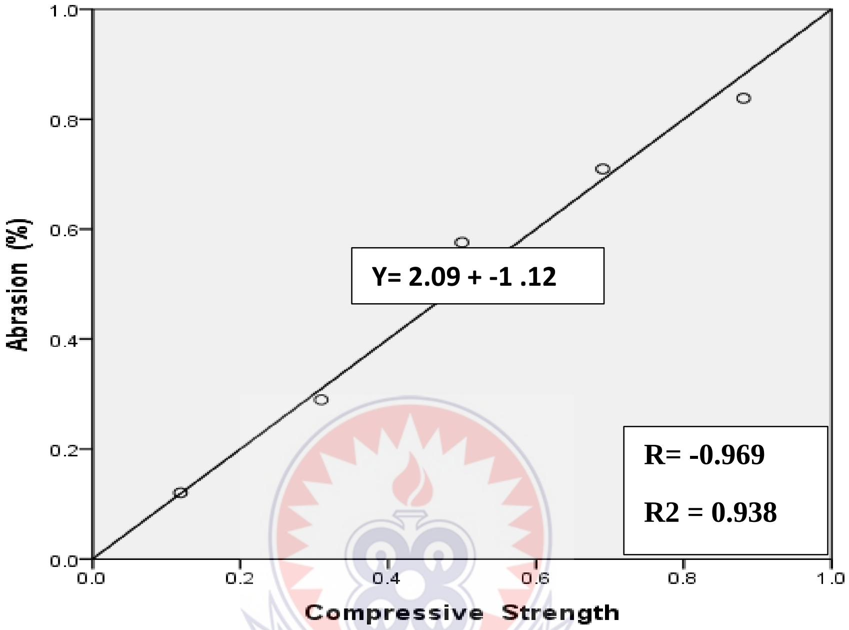


Fig 4.12: Relationship between Abrasion and Compressive strength

CHAPTER FIVE

DISCUSIONS

5.0 Introduction

This chapter presents discussions of the study.

5.1 Discussion of particle size distribution of earth

The results of the particle size distribution of earth used for the study as seen in table 4.1 and figure 4.1 revealed that the earth used for the study contains 0% clay, 0% silt, 49.9% sand, and 50.1% gravel respectively.

5.2 Discussion of particle size distribution of cow dung (CD)

The result of particle size distribution of cow dung used for the study as presented in table 4.2 and figure 4.2 revealed that the particle size of cow dung retained on the 5mm sieve up to the pan were 1.2% , 21.2%,18.6% , 16.6%, 12.4% , 10.8% , 5% , 4.8%, 3.8%, 4% 0.2% and 0.2% respectively. It was observed that 80.8% CD content retained between 5mm sieve to 0.6mm sieve and 19.2% CD retained between 0.3mm sieve to the pan respectively.

5.3 Discussion of the palm fruit fibres

The study revealed that the average length of palm fruit fibres used for the study was 8.3mm and the average diameter was 0.35mm respectively. The fibre aspect ratio of the palm fruit fibres used for the study was 166:7.

5.3 Discussion of density test results

Fig. 4.3 shows the results obtained from the density test of the specimens after curing for 28 days. The results of the study show that as the quantity of CD and PFF content increased, the density of the specimen also decreased. It was found that the control specimens (0%) had a higher density than the reinforced specimens. The percentage reduction of reinforced specimens was between 1.83% (2% CD/0.1 PFF) and 11.73% (10% CD/0.5 PFF) respectively. The decrease in density might be the inclusion of palm fruit fibres which have low density. A similar trend was recorded in the study by Danso (2015); and Kadir et al. (2017)

5.4 Discussion of water absorption test results

Fig. 4.4 shows the water absorption results of the specimens after curing days of 28 days. The results show that the water absorption of the specimens increased with increasing CD and PFF contents. The water absorption ranged from 1.60% (control) to 4.77% (10% CD/0.5 PFF). This result is consistent with the study by Danso et al. (2015) and Kadir et al. (2017) who reported an increase in water absorption as the fibre content in the mixes increased, but inconsistent with the study by Yalley and Manu (2013) who on the other hand reported a reduction in water absorption as the cow dung content increased in the mixes. The increase in water absorption of the specimens may be attributed to the addition of PFF content which makes the specimens porous.

5.5 Discussion of compressive strength test results

The results of the compressive strength test for specimens after curing for 28 days are shown in figure 4.5. The study revealed that as the CD and PFF content increased in the mixes the compressive strength of the reinforced specimens decreased. The values ranged from 1.16 N/mm^2 to 1.02 N/mm^2. Yalley and Manu (2013) reported an increase in compressive strength of about 67% when cow dung was added to earth bricks, but Kadir et al. (2017) reported a 19.52 MPa to 4.13 MPa reduction in compressive strength when (1%, 5% and 10%) palm fibres waste was added to clay fired bricks. The decrease in compressive strength might be the addition of palm fruit fibres content in the mixes.

5.6 Discussion of one-way ANOVA analysis and multiple comparisons of compressive strength

Table 4.4 shows one-way ANOVA analysis and multiple comparisons of the compressive strength of the specimens. The compressive strength analysis revealed that the CD/PFF content negatively influences the compressive strength of the specimens.

Even though the compressive strength of the reinforced specimens decreased but the multiple comparison analysis in Table 4.4 revealed that there are no significant differences between the compressive strengths of the specimens at $P<0.05$. This indicates that all the specimens can equally be used for the same constructional applications such as non-load-bearing walls.

5.7 Discussion of split tensile strength test results

The results of the split tensile strength test are shown in fig. 4.6. The study revealed that as the CD and PFF content increased the split tensile strength decreased. The percentage reduction ranged from 1.59% to 23.02%. The decrease in split tensile strength of the reinforced specimens might be the combination of the cow dung and palm fruit fibres in the mixes. This was expected since the compressive and tensile strengths are the determinant of the mechanical properties of earth bricks (Danso et al., 2015). Furthermore, it was also observed that the control specimen split into two as shown in fig. 4.7a., while as the specimens with CD & PFF content failed, the palm fruit fibres held the brick together after split as shown in fig 4.7b respectively. This implies that the reinforced specimen will be expected to hold a load for some time before complete failure as compared to the control specimens. A similar observation was made by Danso et al. (2015).

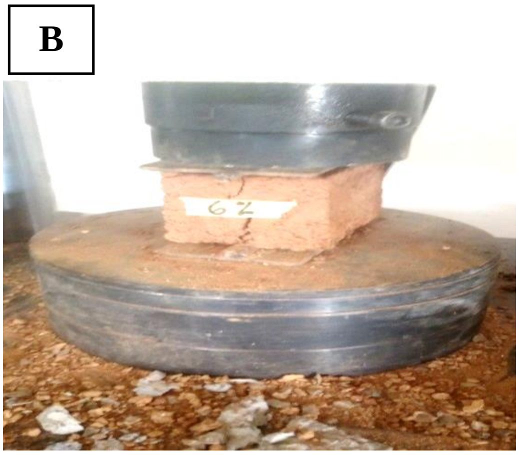


Figure 4.7a

(Unreinforced specimens under Tension)

Figure 4.7 b

(Reinforced specimens under Tension)

5.8 Discussion of one-way ANOVA analysis and multiple comparisons of split tensile strength

Table 4.5 shows one-way ANOVA analysis and multiple comparisons of the split tensile strength of the specimens. The multiple comparison analysis revealed that there are no significant differences between the split tensile strength of the specimens at P<0.05. This indicates that all the specimens can equally be used for the same constructional applications.

5.9 Discussion of abrasion resistance test results

The results of the abrasion test are presented in fig. 4.8. The study revealed that as the CD and PFF content increased in the mixes the abrasion resistance also decreased .The results of this study inconsistence with the study by (Yalley and Manu, 2013) who reported that as the cow dung content increased the abrasion coefficient also increased. Furthermore, Vodounon et al. (2019) also recorded increase in abrasion resistance as the pineapple leaf fibre increased in the mix.

5.10 Discussion of Correlation between the construct

The results of the study revealed a negative relationship between the CD/PFF content and density, compressive strength , split tensile strength and abrasion resistance properties of compressed earth bricks with Pearson correlation coefficient of (R= -0.930, R= -0.971, R= - 0.952, $P<0.05$ and -.981, $P<0.01$ and $P < 0.05$) respectively. On the other hand, the CD/PFF content had a positive correlation with water absorption properties of compressed earth bricks with Pearson correlation coefficient of (R = 0.903 $P < 0.05$ and $P<0.01$) respectively. This implies that as the CD and PFF contents increase in the mixes the density, compressive strength, split tensile strength and abrasion resistance reduces whiles the water absorption also increases with increase in CD and PFF content. The study also revealed that there are significant differences between the CD/PFF content and density, water absorption, abrasion resistance, compressive and split tensile strength at $P<0.05$ and $P< 0.01$.

5.11 Discussion of relationship between density and water absorption

The results presented in Figure 4.9 shows a strong positive relationship between density and water absorption of compressed earth bricks reinforced with cow dung and palm fruit fibres with a coefficient of determination ($R^2 = 0.993$). The study revealed that as the density reduced the water absorption also reduced. The results of this study is inconsistent with the study by Danso et al. (2015) who reported an increase in water absorption and decrease in density when earth blocks were reinforced with sugarcane bagasse fibre.

5.12 Discussion of relationship between splitting tensile and compressive strength

Figure 4.10 presents the relationship between compressive strength and split tensile strength of the compressed earth bricks reinforced with cow dung and palm fruit fibres.

The results of the study revealed a strong positive relationship between splitting tensile strength and compressive strength of compressed earth bricks reinforced with CD and PFF with a coefficient of determination (R 2 = 0.987). This indicates that as the compressive strength decreased the splitting tensile also decreased.

5.13 Discussion of relationship between density and compressive strength

Figure 4.11 shows the relationship between compressive strength and density of the compressed earth bricks reinforced with CD and PFF. The results of the study indicate a positive relationship between density and compressive strength of compressed earth bricks reinforced with CD and PFF with a coefficient of determination of (R^2 = 0.796). This implies that as the density decreased the compressive strength also decreased.

5.14 Discussion of relationship between abrasion resistance and compressive strength

Figure 4.12 shows the relationship between the abrasion resistance and compressive strength of compressed earth bricks reinforced with CD and PFF.

The results of the study revealed a positive relationship between abrasion resistance and compressive strength of compressed earth bricks reinforced with CD and PFF with a coefficient of determination of (R^2 = 0 .938). This indicates that as the compressive strength reduced the abrasion resistance also reduced.

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter comprises a summary of findings, conclusions, recommendations, and suggestions for further studies.

6.2 Summary of Findings of the study

The summary of findings is presented under the following objectives;

- To determine the physical properties (particle size distribution, fibre aspect ratio, density, and water absorption) of compressed earth bricks reinforced with cow dung (CD) and palm fruit fibres (PFF).
- To determine the mechanical properties (compressive strength, tensile strength and abrasion resistance) of compressed earth bricks reinforced with cow dung (CD) and palm fruit fibres (PFF).
- To determine the durability property (abrasion resistance) of compressed earth bricks reinforced with cow dung (CD) and palm fruit fibres (PFF)

6.2.1 Physical properties

The main findings were as follows;

- The density of the control specimen (0%) had a higher density than the reinforced specimens, the percentage reduction of reinforced specimens was between 1.83% (2% CD/0.1 PFF) and 11.73% (10% CD/0.5 PFF).
- The water absorption of specimens reduced as the CD and PFF content increased, which might be due to the inclusion of the fibres which absorb water.
- The results of the study show a strong positive relationship between density and water

absorption of compressed earth bricks reinforced with cow dung and palm fruit fibres with a coefficient of determination of ($R^2 = 0.993$).

6.2.2 Mechanical properties

The main findings were as follows;

- The study revealed that as CD and PFF content increased in the mixes the compressive strength of the reinforced bricks decreased. The decrease in compressive strength might be attributed to the addition of palm fruit fibres in the mixes.
- The One-Way ANOVA analysis revealed that there are no significant differences between the compressive strength of the specimens.
- The split tensile strength of reinforced earth bricks decreased with an increase in CD and PFF content. The decrease in split tensile strength of the reinforced specimens might be the combination of the cow dung and palm fruit fibres in the mixes.
- It was observed from the split tensile strength test that the palm fruit fibres in the reinforced specimens still hold the specimens together after split as compared to the control specimens.
- One-Way ANOVA analysis revealed that there are no significant differences between the tensile strength of the specimens.
- The study revealed a strong positive relationship between compressive and split tensile strength of compressed earth bricks reinforced with CD and PFF with a coefficient of determination of ($R^2 = 0.987$).
- The results of the study revealed a positive relationship between abrasion resistance and compressive strength of compressed earth bricks reinforced with CD and PFF with a coefficient of determination of ($R^2 = 0.938$)

6.2.3 Durability property

- The abrasion resistance of the reinforced specimens decreased with increased in CD and PFF content.

6.3 Conclusions

The properties of compressed earth bricks reinforced with cow dung and palm fruit fibres were investigated. The following conclusions were made:

The density of reinforced specimens decreased from 1.83% (2% CD/0.1 PFF) to 11.73% (10% CD/0.5 PFF). with an increase in CD and PFF content as compared to the control specimens. Also, the water absorption of the reinforced specimens increased from 2.62% up to 4.77% with an increase in CD and PFF content, which might be due to the inclusion of the fibres which absorb water. Also, the compressive strength of the reinforced earth bricks decreased from 1.16% to 13.15% with an increase in CD and PFF content when compared to the control specimens. The decrease in compressive strength of the reinforced specimens might be as a result of the addition of palm fruit fibres in the mixes. Additionally, the split tensile strength of the reinforced specimens decreased from 1.59 % to 23% with an increase in CD and PFF content when compared to the control specimens. It was observed from the tensile strength test that the palm fruit fibres in the reinforced specimens still hold the specimens together after split as compared to the control specimens. Even though the inclusion of the CD and PFF content negatively influenced the compressive strength and the split tensile strength of the reinforced specimens but the One-Way ANOVA analysis revealed that there are no significant differences between the compressive strength and the tensile of the specimens, indicating that all the specimens can equally be used for the same constructional applications such as non-load-bearing walls. Furthermore, the abrasion resistance of the reinforced specimen decreased from 76.47% to 93.53% with an increase in C.D and PFF content lower than the control specimens. This indicates that the combination of the CD and PFF content in compressed earth bricks negatively influenced the water absorption, density, compressive strength, tensile splitting and abrasion resistance. The study revealed a negative correlation between the CD/PFF content and density, compressive strength, split tensile strength and abrasion resistance properties of compressed earth bricks with Pearson correlation coefficient of ($R= -0.930$, $R= -0.971$, $R= - 0.952$ and $R = - 0.981$, $P<0.05$, $P<0.01$, $P < 0.05$ and $P<0.01$)) respectively. On the other hand, the CD/PFF content had a positive correlation with water absorption properties of compressed earth bricks with Pearson correlation coefficient of ($R = 0.903$, $P < 0.05$). Furthermore, the study revealed a negative relationship between density and water absorption with a coefficient of determination ($R^2 = 0.993$). also, compressive strength had a positive relationship with split tensile with a coefficient of determination (R^2= **0.987).**

Additionally, the compressive strength also had a negative relationship with abrasion resistance with a coefficient of determination of ($R^2 = 0.938$)

The study, therefore, concludes that the C.D and PFF inclusion in the compressed earth bricks negatively influences the abrasion resistance and density of the specimens as well as water absorption, compressive and splitting tensile strength.

6.4 Recommendations

- In terms of water absorption, the study recommends compressed earth bricks stabilized with cow dung and reinforced with palm fruit fibres to earthen construction practitioners and users not to use it at places where it will be exposed to direct contact with water due to it high absorptivity of water. Also, the stabilized bricks should be plastered with damp proof cement.
- In terms of density, the study recommends compressed earth bricks stabilized with cow

dung and reinforced with palm fruit fibres for construction practitioners to be used for partition walls due to its low weight.

- In terms of compressive and split tensile strengths, the study recommends compressed earth bricks stabilized with cow dung and reinforced with palm fruit fibres to users not to use them at areas where bricks with high compressive and tensile strengths are need because of its low compressive and split tensile strength.
- In terms of abrasion resistance, the study recommends that compressed earth bricks reinforced with cow dung and palm fruit fibres should be used for non-load-bearing walls such as partition walls since its abrasion resistance was low.

6.5 Suggestions for further studies

1. The chemical analysis of the earth, palm fruit fibres, and cow dung should be conducted to determine their chemical compositions.

2. SEM analysis should be conducted to determine the microstructure of the bricks produce from the mixture of Earth, CD and PPF.

3. Soil from different geographical locations should be used for the same experiment to determine whether similar results will be recorded.

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