UNIVERSITY OF EDUCATION, WINNBA

COLLEGE OF TECHNOLOGY EDUCATION-KUMASI

EFFECT OF SIZE VARIATION OF PALM KERNEL SHELLS AS REPLACEMENT OF COARSE AGGREGATE ON LIGHTWEIGHT CONCRETE.

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FRANK APPIAH-AGYEI

(8181760009)

A thesis in the Department of Construction and Wood Technology Education, Faculty of Technical Education, submitted to the School of Graduate Studies, University of Education, Winneba in partial fulfillment of the requirements for the award of the Master of Philosophy (Construction Technology) Degree.

MAY, 2020

DECLARATION

I, Frank Appiah-Agyei, declare that this thesis with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole for another degree to the University of Education, Winneba or elsewhere.

SIGNATURE: …………………………….

DATE: ……………………………………...

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of dissertation as laid down by the University of Education, Winneba.

SUPERVISOR: DR. HUMPHREY DANSO

SIGNATURE: ………………………………………

DATE: …………………………………………….....

DEDICATION

I specially dedicated this thesis to Almighty God for His Abundance Grace and Mercies upon me to write this piece. May His Name be Praise and Adored in the Heavens and on Earth. I also dedicated this project work to my beloved family.

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Praise to the Almighty God who gave me the strength, guidance and protection in completion of this project work. In the name of God, the Most Gracious and Merciful, I would like to express an immeasurable appreciation to those helping hands to make this work successful.

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Reaching any height is possible but one needs the right shoulders to stand on, that is why I must be grateful to Almighty God for protection and all concern people for my course. I SAY GOD RICHLY BLESS YOU.

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LIST OF ABBREVIATIONS

ACI – America Concrete Institute

BS – British Standard

CSIR – Council for Scientific and Industrial Research

EDS – Energy Dispersive Spectroscopy

EFB – Empty Fruit Bunches

FIP Manual – Federation International de la Percontrainte Manual

HSCA – High Silica Corn Husk Ash

LWA – Light Weight Aggregate

LWAC - Light Weight Aggregate Concrete

LWC – Light Weight Concrete

LWFC – Light Weight Foamed Concrete

MPa – Mage Pascal

MR – Modulus of Rupture

OPS – Oil Palm Shell

OPS(s) – Oil Palm Shells

OPSC – Oil Palm Shell Concrete

PKM – Palm Kernel Meal

PKO – Palm Kernel Oil

PKS – Palm Kernel Shell

PKS(s) – Palm Kernel Shells

PKSC – Palm Kernel Shell Concrete

POME – Palm Oil Mill Effluent

RCA – Regular Corn Ash

SDG(s) – Sustainable Development Goals

SEM – Scanning Electron Microscopy

SSA – Sub Sahara Africa

UN Habitat – United Nations Habitat

USD – United States Dollars

XRD – X Ray Powder Diffraction

ABSTRACT

The utilization of Palm kernel shell (PKS) as alternative to conventional materials for the Ghanaian construction industry is very desirable to promote sustainable development. This is in line with the Sustainable Development Goals (SDGs 11) which promote safe sustainable cities and communities. The purpose of this current study was to investigate the effects of size variation of PKS as coarse aggregate in lightweight concrete. Appropriate sieves were used to get the right various sizes of PKS for this experimental work; these are sizes retained on the sieves 6mm, 8mm, 10mm and 12mm. The study employed a series of mixes which resulted in casting and testing 60 cubes and 60 beams at 7,14,21 and 28 days of curing. The materials phase of this research evaluated the key mechanical properties of hardened concrete, thus compressive strength, flexural strength and density. The compressive strength of the samples increases as the curing age increases. The aggregate sizes 6mm, 8mm,10mm, 12mm and Mixed PKS content, at 7-day recorded an average compressive strength of 3.533 N/mm^2, 3.133 N/mm^2, 3.400 N/mm^2,5.567 N/mm^2 and 4.700 N/mm^2 respectively. The average compressive strength for 28-day of curing were 4.100 N/mm^2, 3.833 N/mm^2, 5.167 N/mm^2, 6.500 N/mm^2 and 5.767 N/mm^2 for aggregate sizes of 6mm, 8mm, 10mm,12mm and Mixed PKS content respectively. Then also the average flexural strength recorded for 28-days of curing were 0.836 N/mm^2,0.936 N/mm^2,1.761 N/mm^2,2.185 N/mm^2 and 1.467 N/mm^2 for the various aggregate sizes 6mm, 8mm, 10mm, 12mm and Mixed PKS content respectively. The average dry density for 28-days of curing were 1509.73kg/m^3, 1497.0 kg/m^3, 1624.13 kg/m^3, 1685.0 kg/m^3 and 1610.47 kg/m^3 for aggregate sizes 6mm, 8mm, 10mm, 12mm and Mixed PKS content respectively. The Scanning Electron Microscopy (SEM) test indicated a highly porous structure of PKS and the Energy Dispersive Spectroscopy (EDS) test was done to find out the chemical composition of PKSC specimens. It can be observed that aggregate size 12mm recorded maximum values for most of the test results. The PKS aggregate size 12mm can be partially mixed with granite to produce a desirable concrete for a sustainable construction. The study concluded that, PKS is useful for concrete production as lightweight aggregate. The use of PKS must be encouraged in order to effectively address the environment pollution caused by indiscriminate dumping and burning of PKS(s).

CHAPTER ONE

INTRODUCTION

1.1 Background

Concrete is the most widely used material on earth after water. Concrete is prepared by mixing various constituents like cement, aggregate, water etc which are economically available (Saravanan and Suganya, 2015). The aggregate typically accounts for about 75% of the concrete volume and play a substantial role in different concrete properties such as workability, strength, dimensional stability and durability. Conventional concrete consists of sand as fine aggregate and gravel, stone, granite or broken block as coarse aggregate. Due to the rapid economic development and growth in the world population, there is a strong demand on natural aggregate usage. Such aggregates are available in many parts of the world and can be used in producing concrete in a wide range of unit weights and suitable strength values for different fields of applications (Neville,1995). The high and increasing cost of constituent materials of concrete has contributed to the non-realization of adequate housing for both urban and rural dwellers. Danso (2016) cited that the United Nations UN Habitat (2005) and Sori (2012) estimated that, about 60% of the population of Africa resides in slums and informal settlement. This situation is primarily caused by rapid growth of urbanization and increase in population, particularly in Sub-Sahara Africa (SSA) without corresponding housing infrastructure (Sori, 2012). Hence there is urgent need to look for alternative construction materials which can produce low cost housing, affordable and sustainable building for everyone. This links with Sustainable Development Goals (SDGs 11) which promote safe sustainable cities and communities. The availability of alternatives to conventional materials for construction industry is very desirable to promote socio-economic development. Palm Kernel Shells (PKS) or Oil Palm Shells (OPS) are organic waste materials obtained from crude palm oil producing factories in Asia and Africa (Alengaram et al., 2010). In particular materials that can complement coarse aggregate and especially if cheaper will be of great interest. The PKS has big potential as material to produce low cost and green building material out of it. This green building material will benefit many as it can be produced locally by indigenous area where the PKS can be found. One of the most obvious benefits to building with green material is the environmental impact and it helps to reduce greenhouse gas emissions, conserves water, reduces waste and consume less energy than conventional material.

Historically, agricultural and industrial wastes have created waste management and pollution problems. However, the use of agriculture and industrial waste to complement other traditional materials in construction provides both practical and economic advantages. Many agricultural wastes like straw and leaves from crops, fibers from fruits, husks and stalks as well as shells contain fibrous content which could be used as ingredient in composite building materials (Chan, 2011; Rowell et al., 1996). The wastes generally have no commercial value and are locally available. Agriculture wastes have advantages over conventional materials in low cost construction (Abdullah, 1997). Researches have been carried out within the last decade on various aspects of Palm Kernel Shell concrete (Abdullah, 1984; Okafor, 1988; Manna & Ganapathy, 2002; Olanipekun et al., 2006; Alengaram et al., 2008a; Osei & Jackson, 2012; Olusola & Babafemi, 2013; Yew et al., 2014; Aslam et al., 2016). Olutoge (1995) investigated the suitability of sawdust and palm kernel shells as replacement for fine and coarse aggregate in production of reinforced concrete slabs. Results of these studies generally suggest suitability for using Palm Kernel Shell as coarse aggregate for lightweight concrete. However, the growing concern of resource depletion and global pollution coupled with an escalating cost of housing has challenged many engineers to seek and develop new materials relying on renewable resources (Adewuyi & Adegde, 2008; Teo et al., 2006a). Palm Kernel shells(PKS) being by-products of the agricultural industry is rampant resource in Ghana, the utilization of this agricultural solid waste as a lightweight aggregate in concrete could reduce the cost of construction since haulage distance would be greatly minimized and also help to resolve the problem of disposal of waste products generated at the palm oil mills. PKS and Periwinkle shell concrete satisfied the bulk density and compressive strength requirement for lightweight aggregate concrete (Eziefula et al., 2017). According to Osei and Jackson (2012), Palm Kernel Shells are hard, carbonaceous, organic by-products of the processing of palm oil fruit. There is a growing interest in waste materials as alternative aggregate materials and significant research is made on the use of many different materials as aggregate substitutes (Ravikumar et al., 2015). Shafigh et al. (2010) carried out a study on mix design and mechanical properties of palm kernel shell lightweight aggregate concrete. They reported that research over last two decades shows PKS can be used as lightweight for producing structural lightweight aggregate concrete. Then also Alengaram et al. (2010) examined the effect of aggregate size and proportion on strength properties of PKS concrete. Their research presented information on the physical and mechanical properties of different sizes of PKS used as lightweight aggregates and their influence on mechanical properties of PKS concrete. They reported it has been found that PKS consists of about 65%-70% of medium size particles in the range of 5-10mm including other two sizes that are (0-5mm) small and (10-15mm) large. The above study used various size ranges of PKS in the lightweight concrete production.

Based on pervious researches, this study will investigate the effects of specific different sizes of PKS as coarse aggregate for lightweight concrete (LWC) production. It is aimed at determining the properties of PKS that will make it suitable for LWC works and the effects of specific different sizes on the strength characteristics of Palm Kernel Shell Concrete (PKSC). It is therefore very vital to use agricultural wastes as a building material to increase sustainable construction in Ghana and the world as whole. Sustainable construction has continued to evolve as that of protecting the world's resources while its true agenda is to control world resources and maintenance of the environment. According to the United Nations is using various interventions to improve sustainable construction by encouraging the use of sustainable materials and appropriate technologies (UN Habitat, 2008).

1.2 Problem Statement

According to Gambhir (2013), the reasons for using aggregate in the production of concrete are due to the economic reasons, volume stability and durability of concrete. Aggregates account for about 60-80 percent of the total volume of concrete depending on the mix design. Extraction and crushing of these aggregates usually involves stripping, drilling, blasting and impact crushing causing pollution and environmental instability which also lead to a total depletion of the natural resources. Ismail (2009) reported that concrete usage is around 10 billion tons per year, which is equivalent to 1 ton per every living person. This high production and consumption of concrete is due to the continuous increase in the production. According to the Global Palm Oil Conference (2015), world production of palm oil and palm kernel oil has grown rapidly in recent years, from about 2 million metric tons in 1961 to over 56 million tons in 2012. Hence, World Bank had estimated that world consumption of palm oil will double by 2020 (Global Palm Oil Conference, 2015). The negative effect of these agricultural activities is high environmental pollution. PKS which results from the palm kernel oil production is openly burnt as a means of disposal releasing significant amount of carbon dioxide (CO_2) in the atmosphere. Therefore, as a means of addressing some of challenges that is the high cost of concrete, depletion of the natural resources and environmental pollution, this study will aim to determine the suitability of using specific different sizes of PKS in concrete production for low cost construction. Through the use of PKS in lightweight concrete production will bring about a significant reduction in the construction cost, reduction in the mining activities for aggregate and environmental pollution. Replacement of conventional aggregates with agricultural and industrial by-products are lightweight aggregates. (Eziefula et al.,2017).

A number of studies have been conducted with PKS in concrete. Olanipekun et al. (2006) compared concrete made with PKS and coconut shells. The flexural behavior of PKSC and OPSC with or without mineral admixture was reported by Alengaram et al. (2008b) and Teo et al. (2006b,c) respectively. Later Jumaat et al. (2009) reported shear behavior of PKS foamed concrete and found out that aggregate interlock behavior of PKS contributes significantly to shear strength. Furthermore, Oyejobi et al. (2012) examined the effect of PKS range sizes and mix ratio on lightweight concrete. Four levels of concrete were adopted using various sizes ranges at various percentages as follows; sample A(5-

15mm)100%, sample B(5-10mm)100%, sample C(0-5mm)40% and (10-15mm)60% and sample D(5-10mm)70% and (10-15mm)30%. The study found that the sample A which contains 100% of PKS in the range (5-15mm) gave the maximum values of densities and compressive strengths. In past research works, all sizes or range of sizes of PKS have been used as a complete or partial replacement for gravel or coarse aggregate. No study has used the specific sizes (size variation) of PKS in concrete. This study therefore intends to investigate the effects of specific different sizes in the production of lightweight concrete with PKS as coarse aggregate.

1.3 Aim

The aim of the study is to investigate the effects of size variation (specific sizes) of Palm Kernel Shells (PKS) as coarse aggregate in lightweight concrete.

1.4 Specific Objectives

The specific objectives are:

1. To determine the dry density of lightweight concrete produced with different sizes of PKS.
2. To investigate the compressive strength of the lightweight concrete produced with different sizes of PKS.
3. Investigate the flexural strength of the lightweight concrete produced with different sizes of PKS.
4. To analyze the microscopic nature of the lightweight concrete produced with PKS.

1.5 Research Question

- What will be the dry density values for lightweight concrete produced with different sizes of PKS?
- What will be the compressive strength values for the lightweight concrete produced with different sizes of PKS?
- What will be the flexural strength of the lightweight concrete produce with different sizes of PKS?
- How would the microscopic nature of the lightweight concrete produced with PKS be analyzed?

1.6 Significance of Study

The study investigated the strength properties of the lightweight concrete. The agricultural by-products such as palm kernel shells are hard which will improve the compressive and tensile strength to resist load. The growing concern of resources depletion and global pollution has challenged many engineers to seek and develop new materials relying on renewable resources. These include the use of by-products and waste materials in building construction. Then also many of these by-products are used as aggregate for the production of light weight concrete (LWC). Although there have been several research works on PKS as light weight aggregate for production of light weight aggregate concrete (LWAC) but consideration of the various specific sizes to produce LWAC has not yet done. In Ghana, there is an annual production of huge tons of PKS waste in various parts of the country.

Figure 1 shows a photo of PKS wastes being left at mill area.

Figure 1.1 PKS left at mill area

According to Loehr (1984) the exponential growth rate of population, development of industry, technology and the growth of social civilization would be considered as underlying factors that have caused the increased waste production. Nowadays the importance of counter measures to deal with waste materials has been pointed out because such materials continue to increase in each and every year. The use of alternative aggregate has become necessity to the construction industry due to the economic, environmental and technological benefits derived from their use. The study contributes to knowledge on the properties of the PKSC and it serves as a reference for researchers in the construction field. Furthermore, the findings can be used as a guideline for stakeholders in the construction industry particularly, building contractors, general public and government. Then also this study enables stakeholders involve to use agricultural by-products such as PKS for production of concrete which would reduce the negative environmental impact on the society.

1.7 Scope of the Study

Aggregate grading is an important element in concrete mixing and the resultant compression strength. An experiment was conducted to determine the effects of specific different aggregate sizes on the compressive strength of concrete produced with PKS. The experiment used four treatments for various PKS sizes (6mm,8mm,10mm and 12mm) including the mixed up of all different sizes of PKS up to 12mm.The mixed up sample is comprised of 25% of each size of PKS. This study compared the results with each size using PKS as coarse aggregate. Many studies had PKS as coarse aggregate using various size ranges as treatments but this study used specific size for the lightweight concrete in the laboratory. The sand used in this experiment was locally available river sand. Cement was used as a stabilizer for all samples including the mixed up in this study and its performance compared to lightweight concrete with each treatment size.

1.8 Structure of the Thesis

This thesis comprises the following sections. Chapter one introduces the background of the research, problem of statement, purpose of the study, objectives of the study, research questions, scope of work, significance of the study and structure of the study. Chapter two (2) comes up with the literature review on palm kernel shell, history of concrete production; elaborate the agricultural and industrial by-products as construction materials from pervious study. Chapter three (3) explains the methodology used in this study, from the materials preparation, equipment, concrete production and curing method. Chapter four (4) comprises testing of aggregate particles and the specimens for PKS concrete. Chapter five (5) delivers the information about lightweight concrete in this study from the aspect of physical, mechanical and chemical properties including the findings and interprets of results from the experimental investigation. Chapter six (6) concludes all the work done and provides recommendation for future study.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This research deals with a variety of issues in the literature and previous research works which are related to this study. This chapter is very appropriate because it provides the historical, theoretical and practical information considered necessary to establish a methodology for the research.

2.1 History for Building Materials

In the days ago materials used to build house for human in the pre-historical era has been recorded by researchers with opposing periods and dates. For example Middendorf (2001) as cited in Al-sakkaf (2009) indicated that recorded cases of the use of soil and soil bricks/blocks date back to Mesopotamia "around 800 BC". In Al-Sakkaf (2009) also indicated the record use of soil for building houses in Mesopotamia as far back as 10,000 BC. In addition, Fullerton (1984) also traced the history of the use of soil material for housing to the days of Pliny who in AD 67 recorded the existence of soil built watch-towers by Hannibal, the famous Carthaginian general almost 300 years before. Due to these opposing periods and dates given, what reason can be deduced from this historical moment and it was presented that soil is building material used by man to build shelter after moving out from the cave shelter. This deduction is supported by Reddy (2004) as cited in (Al-sakkaf,2009) which showed that historically some of the building materials are new while others are very old and started with human shelter. In order to clear any doubt Reddy (2004) studied the historical development of other building materials and presented their chronological sequence as shown in the Table 2.1

Table 2.1 Chronological Sequence Development for Building Materials

Building Material	**Period**
Soil, stones, wood and thatch	Prior to 8000 BC
Sun dried bricks	6000 BC
Pottery products	4000-8000 BC
Brunt bricks	4000 BC
Lime	3000 BC
Glass	1300 BC
Iron products	1350 BC
Lime – pozzolana cement	300-476 AD
Aluminium	1808 AD
Portland cement	1824 AD
Plastic	1862 AD

Source: Reddy (2004) as citied in Al-Sakkaf (2009)

Soil in many tropical and hot regions has properties which, with a lot of sun and dry air, is favorable to make durable walls. Archaeological evidence indicates that soil materials such as cob and rammed soils were highly a popular building material for both domestic and commercial houses in very dry climates. Some of the ancient structures built entirely of soil materials are still famous to date and Fullerton (1984) stated some examples namely; Luxor in Egypt; the soil-built traditional savanna architectural houses in Kano in northern Nigeria; Timbuktu in Mail; churches, community centers and houses by the early European settlers and missionaries in some parts of Africa are typical examples. The use of soil material in Ghana for domestic and commercial purpose equally follows the world trend as majority of houses have been built with soil materials (Hammond 1984; Ayensu,1991; Gidigasu,1993) as cited in Osei-Tutu and Ofori (2009). Examples of soil –built structures are the famous Islamic Heritage Mosques, Royal Palaces and Dwelling houses in Northern Ghana, Larabanga Mosque in Damongo and Nakori Mosque in Wa, the chiefs' palaces at Wa, Jirapa, Nandom and Fielmuo all in Upper West Region. Then also both Elmina and Cape Coast Castles were built with soil in 1482 and 1653 respectively.

2.2 History of Concrete Production

Construction of building is an ancient human activity which began with the merely functional need for a controlled environment to moderate the effects of climate. Constructed shelters were one means by which human beings were able to familiarize themselves to a wide variety of climates. According to Riza (2017) around 4500 BC traced of the fired brick which was found in Indus Valley cities. Circa 500-300 BC, the Greek have had the knowledge to mix pozzolan with lime mortars in order to make it hydraulic by adding highly siliceous, volcanic santoria earth (Idom, 1997). However, application of pozzolan in concrete around 25 BC in a famous book written by Vitruvius (1932), De

Architectura-Book 11, these words were written in that book "Est etiam genus pulvevis quod efficit naturaliter res admirandas" which means there is also a kind of powder which due to its nature gives excellent result to the strength and durability of the concrete. The powder refers to pozzolanic material which turned out to produce better concrete compared with that of pure lime in aspect of strength and durability with support of superior workmanship. On the contrary, the superiority of pozzolan in the Roman concrete was used during Roman Empire and slowly faded away along with the collapse of the empire. Unfortunately, the Roman concrete has no proper mix proportion and disclosed of pozzolan source which were exclusively a problem including the decreasing of workmanship, these factors led to make Roman concrete forgettable. Hence the knowledge of this remarkable concrete also disappeared. With the fall of the Roman Empire, earth masonry application still became the main building technique that was used across the globe until the invention of Portland cement. The use of earth masonry started to be replaced by modern concrete. The cement production is growing so fast as the economies emerge and concrete now become the most consumed material in earth after water (Hewlett,1998).

This recent study will be worked out in the viewing of making the lightweight concrete produced with abundantly available PKS especially in the benefit of cost effectiveness and environmental issues concerning waste materials disposal and reduction of carbon dioxide emission.

2.3 Agricultural Wastes as Building Materials

Palm Kernel Shells are wastes from the agricultural sector and they are available in large quantities in the tropical regions. Mostly palm tree is one of the most important agricultural and commercial plantation crops in Ghana. People recognized it as a tree of life because every part of the palm tree such as fruits, trunks, leaves and shells of the fruits can be effectively utilized for living (Ahmad et al., 2010). According to Yalley (2012) as cited in Danso (2016), in Africa conventional building materials are imported or manufactured in urban towns and have to be transported to other parts of a country at long distances which makes the materials very expensive and invariably increases the cost of housing. The high cost of conventional building materials is a major factor affecting housing delivery in Ghana. This has necessitated research into alternative materials for construction and this study's main objective is to encourage the use of these seemingly waste products as materials for low-cost housing. It is also expected to serve the purpose of encouraging estate developers in investing these materials in construction. Following a normal growth in population, the amount and type of waste materials have increased accordingly. Many of the non-decaying waste materials will remain in the environment for hundreds, perhaps thousand years. The non-decaying waste materials cause a waste disposal crisis, thereby contributing to the environmental problems. Besides the environmental impact can be reduced by making more sustainable use of these wastes. The sustainability means how to reduce, reuse or recycle waste, the latter being the preferred option of waste disposal.

A research effort has been done to match society's need for safe and economic disposal of waste materials. The use of waste materials saves natural resources and dumping spaces and helps to maintain a clean environment. The current concrete construction practice is thought unsustainable because not only is it consuming enormous quantities of stone, sand and drinking water but also the high demand of coarse aggregates which involves stripping, drilling, blasting and impact crushing causing pollution and environmental problems.

Rising construction costs and the need to reduce environmental stresses to make construction sustainable has necessitated research into the use of alternative materials especially locally available ones which can replace conventional ones used in concrete production.

The use of waste materials in construction contributes to conservation of natural resources and the protection of the environment (Ramezanianpour et al.,2009). Then also Nimityongskul and Dalader (1995) investigated the use of coconut husk ash, corn ash and peanut shell ash as cement replacement in concrete production. Ndoke (2006) investigated the suitability of PKS as partial replacement for coarse aggregate in asphaltic concrete. In addition, Olutoge (1995) investigated the suitability of sawdust and PKS as replacement for fine and coarse aggregate in the production of reinforced concrete slabs. He concluded that 25% sawdust and PKS substitution reduced the cost of concrete production by 7.45%. Olanipekun (2006) also compared concrete made with coconut shells and PKS as replacement for coarse aggregates and concluded that coconut shells performed better than PKS as replacement for conventional aggregates in the concrete production. The aggregates typically account for about 75% of the concrete volume and play a substantial role in different concrete properties such as workability, strength, dimensional stability and durability. Conventional concrete consists of sand as fine aggregate and gravel, stones or granite/broken blocks in various sizes and shapes as coarse aggregate. There is a growing interest in waste materials as alternative aggregate materials and significant research is made on the use of many different materials as aggregate substitutes (Ravikumar et al,2015). Furthermore (Shafigh et al, 2010) carried out a study on mix design and mechanical properties of PKS lightweight aggregate concrete. Then also Ata et al., (2006) compared the mechanical properties of PKSC with that of Coconut Shell Concrete and reported the economy of using PKS as lightweight aggregate. They reported that research over the last two decades shows that PKS can be used as lightweight aggregate for producing structural lightweight aggregate concrete.

2.4 Binding Agents

The binding agent plays an important role in creating bonding between concrete constituents. In this research work the term binding agent is the same as binder/stabilizing agent in as much as it connects to its role to bind fine and coarse aggregates for concrete production. Makusa (2012) defined stabilizing agents as primary binder (hydraulic) or secondary binder (non-hydraulic) materials that when in contact with water or in the presence of pozzolanic materials react with water to form cementitious composite materials. The author outlined the regularly used binder as cement, lime, fly ash and blast furnace.

2.4.1 Cement as a Binder

Cement is the most commonly binding agent used in concrete production. Cement, a finely grained compound is a mixture of clinker and gypsum that have been ground into a fine powder. Cement is one of the critical materials used in concrete as a binding agent and it has a significant impact on the strength of the concrete. It may be considered as the stabilizing agent or hydraulic binder since it can be used alone to bring about the stabilizing action required (Al-Tabba & Evans 2005, Sherwood,1993; Eurosoilstab,2002 as cited in Makusa,2012). Hydration process starts when cement is mixed with water and other components for a desired application resulting into hardening state. The hydration reaction is slow proceeding from the surface of the cement grains and center of grains may remain unhydrated (Sherwood,1993). Cement hydration is a complex process with a complex series of unknown chemical reactions (Mac Laren & White,2003). Hydration process can be affected by presence of foreign matters, water-cement ratio, curing temperature, additives and specific surface of the mixture. Calcium silicates C_3S and C_2S are the two main cementitious properties of Ordinary Portland cement responsible for strength development (Al-Tabba & Evans 2005; Eurosoilstab,2002 as cited in Makusa,2012). Calcium hydration is another hydration process of Portland cement that further cementitious material in the concrete mix (Sherwood,1993). In general, the strength of concrete depends on the way the cement is stored or concrete mixing, curing, casting, hydration and many other factor. In some cases, cement with a lower grade can be used to make stronger concrete than higher quality cement that has been stored for a long time in degradable condition. Table 2.2 gives the summary of the oxide composition of the main compounds of Ordinary Portland cement which is commonly used in Ghana (Gambhir, 2002).

Table 2.2 Chemical Analysis for Ordinary Portland Cement

Compound	Oxide	Percent by Weight
Lime	Calcium(Ca O)	60-67
Silica	Silicon (SI O_2)	17-25
Alumina	Aluminium (Al_2 O_3)	3-8
Ferrite	Iron (Fe_2 O_3)	0.5-6
Magnesia	Magnesia (Mg O)	2.5
Potash and Soda	Sulphur trioxide ($S0_3$)	1

Source; Gambhir (2002).

2.4.2 Lime as a Binder

Not many people are aware that the use of lime as binder in concrete preceded the use of pottery (Kingery,1980). Even though, many believed that concrete was invented by the Romans, archaeological evidence showed that concrete was discovered during Neolithic age (Malinowski & Garfinkel,1991), long before the Greeks (Koui & Ftikos,1998) and Phoenicians (Baronio et al.,1997). The discovery of binding properties of lime was probably discovered when Neolithic people that lived in natural cave carved in limestone, used fire to heat or to cook. It was not far-fetched to find out the binding properties of lime in the way that quicklime easily hydrates in the presence of water and hardens in air (Aitcin,2008). Through heating process of calcium carbonate $CaCO_3$ is released, then in hydration or slaking process lime absorbs the water until the carbonation process then lime will re-absorb the carbon dioxide (CO_2) again. Because of the additional chemical content to make lime more hydraulic, the natural composition of lime will decrease and this will lead to more hydraulic lime, the less CO_2 is reabsorbed during set. Lime stabilization may refer to pozzolanic reaction in which pozzolan materials react with lime in presence of water to produce cementitious compounds (Sherwood,1993; Eurosoilstab,2002 cited in Makusa,2012). The effect can be brought by either quicklime Ca O or hydrated lime, $Ca(OH)_2$. Slurry lime also can be used in dry soils conditions where water may be needed to attain effective compaction (Hicks,2002). Quicklime is the most commonly used lime. Sherwood (1993) explained that quicklime when mixed with wet soil, instantly takes up to 32% of its own weight of water from surrounding soil to form hydrated lime, generated heat accompanied by this reaction will further cause loss of water due to evaporation which in turn results in increased plastic limit of soil. Natural pozzolanas materials containing silica and alumina have great potential to react with lime (Makusa,2012). However, presence of Sulphur and organic material may slow down the lime stabilization process. Lime is preferred to cement stabilization in places where it is locally available and in situation where the soil has particularly high clay content (Brown,2009). Calcium carbonate in various types of limestone are burnt and slaked to produce hydrated, hydraulic or natural-hydraulic lime. Normally, the natural-hydraulic lime is mixed with the soil to produce stabilized soil blocks (Attoh-Okine,1990; Brown,2009). Pozzolanic reactions with lime such as mixing with fired brick powder or burnt rice husks or similar alkali strong plants, provide a type of potash (potassium carbonate) that will form similar properties to that of Ordinary Portland cement. The chemical composition and analysis of lime has been determined and established by previous research studies (Attoh-Okine,1990). Table 2.3 presents the chemical composition and analysis of lime.

Table 2.3 Chemical Analysis of lime

Oxide	Percent by Weight
Quicklime (Ca O)	61.5
Magnesium (Mg O)	2.41
Aluminium (Al_2O_3)	1.95
Iron (Fe_2O_3)	0.81
Potash and Soda (SO_2)	11.62
Ignition loss	20.16
Insoluble residue in hydrochloric acid	15.45
Free moisture	0.42
Insoluble material in Na_2 Co_3	0.42
Available lime	35.05

Source: Attoh-Okine (1990)

2.5 Industrial and Agricultural Waste as A Construction Material

Pozzolanas are fine silica and alumina rich materials which when mixed with hydrated lime produce cementitious materials suitable for stabilization and construction purposes. Pozzolanas are commonly used as an addition (which can be called "Cement Extender") to Portland cement concrete mixtures to increase the long term strength and other material properties of Portland cement concrete and in some cases reduce the material cost of concrete (Yalley,2012). Bediako and Frimpong (2013) looked at the importance of pozzolanic materials in construction as economic, ecological and technical. In the economic sense, the production of pozzolanic materials is far less expensive than Portland cement because energy is one of the major cost components in cement industry. The pozzolana producing companies use almost half of the energy which is used to produce Portland cement, this has a net effect on cost reduction with respect to pozzolana utilization. The production of less expensive pozzolana material could lead to affordable concrete and mortar including less expensive building. Moreover, approximately $ 100 million could be saved from cement importation through the use of locally produced pozzolana in Ghana. From the ecological perspective, the added pozzolana materials contribute little effect to the environment as compared to cement production in terms of CO_2 emission. Technically, they argued that since pozzolanic materials refine pore structure of cement by making it denser, it will mean that there will be reduction of chemical attacks early shrinkage and minimize the leaching action of cement compounds. These conventional materials industries created enormous environmental problems to the planet and our country. Researchers have over many years researched extensively on alternative waste materials such as fly ash, silica fume, ground granulated blast furnace slag, rice husk ash, palm oil fruit ash, paper sludge, palm kernel shells, coconut shells etc. to replace the conventional materials.

2.5.1 Fly-Ash as a Binder

Fly-ash is derivative of coal fired electric power generation facilities, it has little cementitious properties compared to lime and cement. Most of the fly ashes belong to secondary binders which cannot produce the desired effect on their own. Nevertheless, in the presence of a small amount of activation, it can react chemically to form cementitious compound that contributes to improve strength of soft soil (Makusa,2012). According to FMS-410(1992), fly ashes are readily available, cheaper and environmentally friendly. There are two main classes of fly ashes; class C and class F. They added that, class C fly ashes are produced from burning sub-bituminous coal which has high cementitious properties because of high content of free Ca O. Class C from lignite has highest Ca O (above 30%) resulting in self cementing.

Class F ashes are produced by burning anthracite and bituminous coal which has low self-cementing properties due to limited amount of free Ca O available for flocculation of clay minerals and as a result require addition of activators such as lime or cement. The reduction of swell potential achieved in fly ashes treated soil relates to mechanical bonding rather than ionic exchange with clay minerals (Makusa,2005).

2.5.2 Blast Furnace Slag

According to Yalley (2012) blast furnace slag and pulverized fuel ash are the two waste materials which are being used to the greatest degree in construction. He added that blast furnace slag is used to the extent that 80% of what is available is used and in several countries virtually all that is produced is used. The slag is considered as a highly satisfactory material as a pozzolana.

2.5.3 Pulverised Fuel Ash

It can be fou\nd in Yalley (2012), pulverized fuel ashes are about 20% used overall but up to 70% is used in some countries. A large amount of these two materials are used as binders but many more complicated uses are being developed. These materials can make a particular contribution in conserving energy in the manufacture of cementitious materials and lightweight aggregates. However, the total proportion of mineral wastes which is used only about 5% of that produced and most is used in comparatively low grade application such as fill in roads and embankments. Sherwood (1993) as cited in Makusa (2005) itemized Pulverised fule ash in three forms depending on cooking system which include: air cooled slag, granulate or pelletised slag and expanded slag.

2.5.4 Sugarcane Wastes

Sugar cane waste has recently been tested in some parts of the world for its use as a cement replacement material. The waste was found to improve some properties of the paste mortar and concrete including compressive strength and water tightness (Oliveira, 2009). The higher silica content may vary from ash to ash depending on the burning conditions and other properties of the raw materials including the soil on which the sugar cane is grown. It has been reported that the silicate undergoes a pozzolanic reaction with the hydration productions of the cement and results in a reduction of the free lime in the concrete. Frias et al., (2004) looked at the characteristics of sugar cane straw waste as pozzolanic material for construction and found out that, its ash calcined at 800 and 1000 C has high and similar pozzolanic reactivity. From the above studies, it is therefore worth researching into the use of sugar cane ash as stabilizer to soil for blocks production.

2.5.5. Corn Husk as a Binder

Utilization of high-silica corn husk ash (HSCA) as supplementary cementitious materials (SCM) has the potential to benefit the environment, as well as corn and cement producers (Kevern & Wang, 2010). The authours investigated into pozzolanicity of corn husk ashes as supplementary cementitious material in concrete and reported that mortar with up to 10% HSCA replacement for Portland cement developed comparative compressive strength values (20%) than samples produced using the regular corn ash (RCA). Furthermore, Yalley and Aseidu (2013) also conducted a study to investigate the potential of corn husk as an enhancer for the production of soil blocks for low cost housing and found that stabilizing soil with corn husk ash can improve the properties of soil and blocks making them suitable for use as a building material for the construction of load bearing walls.

2.6 Plantation History for Oil Palm Tree in Ghana

Palm kernel shells (PKS) are derived from the oil palm tree (Elaeisguinensis), an economically valuable tree and native to Western Africa and widespread throughout the tropics (Omange, 2001). Palm kernel oil residue and shells are by-products obtained from the processing of the kernel of the fruit for the oil palm. According to Sundram et al (2003) the genus Elaeis comprises two species namely Elaeis Guinensis (E. Guinensis) and Elaeis Oleifera (E.Oleifera). Adzimah and Seckley,(2009) and Poku,(2002) as cited in Acheampong,(2015) found that the three main species of oil palm tree (E.Guinensis) are Dura, Pisiphera and Tenera. In Ghana the oil palm tree is derived from the Elaeis guinensis specie and it is found mostly in the southern parts of the country. The Council for Scientific and Industrial Research (C.S.I.R, 2006) Ghana has more than 125,000 hectares of land under oil palm cultivation which are mostly under the nucleus estate model, typified by a large central plantation surrounded by smaller plantations established on local farmers' land. However, oil palm cultivation is not limited to these nucleus estate model but some plantations are located in the Ashanti, Eastern, Western, Ahafo and Volta Regions of Ghana.

In Ghana, it is estimated that over 243,852 tons of oil palm fruits are produced annually of which the shells form almost 30% (Danyo, 2013; Fold &Whitfield, 2012; Teo et al., 2006b; Agbodeka, 1992). The improper disposal of the shells has raised environmental issues such as pollution and degradation, due to this the utilization of PKS as aggregates for lightweight concrete production has a strong perspective of attracting investors into the oil palm production sector which will help the national economy to expand in terms of financially. By substituting PKS concrete for normal weight concrete, a saving on self-weight of up to 42 percent can be realized (Olanipekun et al., 2006).

2.6.1 Palm Kernel Shells (PKS) As A Coarse Aggregate

Palm kernel shells are agricultural solid end products of oil palm manufacturing processes. Palm trees grow in regions where temperature is hot with copious rainfall such as Malaysia, Indonesia, Nigeria and Ghana. Studies have shown that the utilization of OPS as LWA in the production of LWAC since 1984 in Malaysia by Abdullah. Palm oil production is a significant industry in Malaysian economy and it is among the largest producers in the world market. After the production of oil palm there are by-products from the process such as empty fruit bunches (EFB), palm kernel shells (PKS) and palm oil mill effluent (POME). These by-products are some of the wastes produced during the palm oil processing.

Nowadays, a large amount of OPS waste materials stockpiled and dumped which cause storage problems within the vicinity of factories as large quantities of these wastes are produced every day. In Malaysia it is estimated that over 4.6 million tons of OPS are produced annually as waste. A number of studies over the last two decades showed that OPS can be used as LWA in order to produce structural LWAC with a reduction in density of 20-25% compared to normal weight concrete. PKS are hard substances of the palm kernel fruit that surround the palm seeds. According to Mohd et al. (2008) PKS possesses a hard characteristics as coarse aggregate traditionally used for concrete production. In addition, Olutoge (1995) said that PKS is the hard endocarp of palm kernel fruit that surrounds the palm seed. It is obtained as crushed pieces after threshing or crushing to remove the seed which is used in the production of palm kernel oil. Then also Abdullah (1996) found that palm oil processing has six stages namely; sterilization, threshing, pressing, depericarping, separation of kernel and shell and clarification. PKS is obtained as crushed pieces, the sizes of which vary from fine to coarse aggregates, after crushing of palm kernel to remove the seed, which is used in the production of palm kernel oil (Olutoge, 1995). The colour of the shells ranges from dark grey to black with a variety of shapes such as curved, flaky, angular, polygonal, elongated, roughly, parabolic and other irregular shapes depending on the breaking pattern of the nut (Teo et al., 2006b). The surface of the shells is fairly smooth for both the concave and convex faces with rough and spiky broken edges. PKS are hard in nature and do not deteriorate easily when used for concrete or leach to produce toxic substances (Basri et al., 1999). The thickness varies and depends on the species of palm tree from which the palm nut is obtained and ranges from 0.15-8mm (Shafigh et al., 2010; Teo et al., 2006b; Basri et al., 1999; Okpala., 1990). PKS is light and therefore ideal for substitution as aggregate in production of LWC. In recent years, many research works on the use of PKS as LWA to produce LWAC have been carried out (Abdullah, 1984; Mahmud & Ganapthy, 2002; Olanipekun et al., 2006; Alengaram et al., 2008; Mahmud et al., 2009; Jumaat et al., 2009). Most of the above researchers used PKS of all sizes after removing the dust and fibers, the maximum sizes of PKS is found to be about 15mm. Though the sizes of PKS may vary depending upon the type of machinery used to crack the palm nuts, generally the size of shells are in the range of 2-15mm. In the past, research works carried out on PKS focused on using the shells of different sizes above 3mm after removing smaller particles less than 3mm. The results showed that using PKS as LWA structure grade concrete of compressive strength of about 15-25 MPa could be produced (Mannan et al., 2002). Generally, the strength properties of LWAC are influenced by aggregate parameters such as size, shape, roughness and stiffness. In addition, the LWA cement matrix bond plays a very important role in strength development (FIP Manual, 1983). Okafor (1988) reported that the Palm Kernel Shell Concrete (PKSC) also referred as Oil Palm Shell Concrete (OPSC) in some parts of the world. Olanipekun et al, (2006) compared concrete made with PKS and coconut shells. The flexural behavior of PKSC or OPSC with or without mineral admixture was reported by Alengaram et al. (2008a) and Teo et al. (2006) respectively. They reported that the performance of PKSC was superior with respect to ductility. Later Jumaat et al (2009) reported shear behavior of PKS foamed concrete and found out that aggregate interlock behavior of PKS contributes significantly to shear strength. In past research works, all sizes of PKS have been used as a complete or partial replacement for gravel or coarse aggregates. Furthermore, Oyejobi et al. (2012) examined the effect of PKS sizes and mix ratio on lightweight concrete. Four levels of concrete were adopted using various sizes ranges at various percentage as follows: Sample A(5-15mm)100%, Sample B(5-10mm)100%, Sample C(0-5mm)40%&(10-15mm)60% and Sample D(5-10mm)70%&(10-15mm)30%. The study found that the sample A which contained 100% of PKS in the range (5-15mm) gave the maximum values of densities and compressive strengths respectively. Based on the previous studies, PKS possess similar characteristics as coarse aggregates which encourage their use as replacement for conventional granite aggregates. PKS aggregate has a unit weight of between 500 and 620 kg/m^3 (Teo et al, 2006b; Mannan & Ganapathy, 2001) and this is approximately 60% lighter than conventional granite aggregates. The shells have a porosity of 37% with loose and compacted bulk densities of 545 and 595 kg/m^3 respectively (Mannan & Ganapathy, 2001; Okpala, 1990). This implies that the material is within the range of bulk densities for lightweight aggregate 300 to 1100 kg/m^3 (Neville and Brooks, 2008). The density of fresh PKS concrete are found to be in the range of 1753-1763 kg/m^3 (Okafor, 1988) depending on the mix proportions, the use of river sand and the water-cement ratio.

Okpala (1990) reported that the slump and compacting factor values of the PKS concrete is increased with water cement ratio and decreased with increased aggregate content. It has been found that PKS lightweight concrete has a good thermal conductivity for low cost housing (Harimi et al.,2007). This advantageous property of a good thermal performance is due to the high porosity which results in low specific gravity. Alengaram et al. (2008a) improved the mechanical properties of PKS concrete by incorporating 10% silica fume and 5% of fly ash by weight of cement. The superplasticizer used was 1% of weight of cement. Silica Fume (SF) has the ability to localize at the surface of the aggregates (Neville 1995) to enhance the bond between an aggregate and the concrete matrix. The extremely fine SF particles react with liberated calcium silicate and aluminate hydrates in concrete. The increased strength and reduced permeability are caused by making the matrix of the concrete dense (Robert et al., 2003). The fresh density of the PKS concrete was found to be approximately 1880 kg/m^3 which is about 20% less than the density of normal weight concrete. Additionally, measured slump values for PKS concrete averaged 65mm which showed that the PKS concrete had a good consistency (moderate workability). In order to have sustainable buildings the possibility of using PKS as construction materials will be highly suitable.

2.7 Aggregate for Concrete

Aggregates are one of the major elements for concrete. The right and quality of aggregates cannot be compromised while making concrete. Studies have shown that fine and coarse aggregates are very important in concrete because aggregates occupy 60% to 75% of concrete volume and strongly influence the concrete's freshly mixed and hardened properties, mix proportion and economy (Neville & Brooks,2008; Alexander & Mindness,2005; Quiroga & Fowler,2004). The essential requirement of an aggregate for concrete is that it remains stable within the concrete both in the fresh and hardened states and in any given environment, throughout the design life of the concrete (Smith & Collis,1993). PKSC is different compared in terms of the constituent materials. PKSC is composite materials that contain cement as the binder, cementitious material, fine aggregate such as sand but the coarse aggregate replaced by the PKS. Hence, the PKS acts as coarse aggregate in this type of concrete. The PKS used as a coarse aggregate can be crushed or uncrushed type. The crushed PKS have irregular sizes of shapes, different sizes of the shells, different thickness of the shell and having low density compared with the conventional aggregate. Whereas for the uncrushed PKS, the shapes are spherical and it can be smooth or rough depending on the extraction process. The low bulk density of PKS can produce lightweight hardened concrete. These LW concrete are very useful in construction industry since the LWC can reduce the weight of structural members. Thus it can reduce the dead load of the structure and reduce the use of reinforcement steel which leads to the overall cost reduction in construction project.

2.7.1 Classification for Aggregate

Aggregates can be classified in different means such as the specific gravity, size and source. Firstly, based on the specific gravity three categories being normal weight aggregate, lightweight aggregate and heavyweight aggregates can be produced (Neville & Brooks, 2008; Andaleeb, 2005; Kosmatka et al., 2003). Secondly, on the basis of size, one can differentiate between the fine aggregates consisting mostly of small materials passing No.4 sieve and retained on No.200 sieve and coarse aggregates that mostly consist of large particles retained on the 4.75mm(No.4) sieve (ASTM C136-01,2001). Fine aggregates are made of natural gravel and sand which are dug from a pit, river, lake or seabed. The normal acceptable range for coarse aggregates is between 5mm and 40mm and they are made from crushing quarry rock, boulders, cobbles or large size gravel. Lastly, the source classification of aggregates can be natural and artificial. Natural aggregates are formed from weathering and abrasion process or by crushing a larger parent rock artificially while artificial aggregates are larger depending on the manufacturing process or industrial by-products. Pumice, scoria, tuff, PKS and other materials of volcanic origin are lightweight aggregates from natural source. Expanded blast-furnace slag, clinker, fly ash, vermiculite and expanded perlite which are man-made lightweight aggregates (Chandra & Berntsson, 2002; Owens, 1993; Popovics, 1992).

Moreover, there are many types of aggregates available that can be classified as lightweight aggregates (LWA), with a wide range of properties. Some examples of LWA include; leca, pumice, perlite, vermiculite, diatomite, scoria, shale, clay, slate, sintering grate, expanded shale, fly ash and palm oil shells (Neville & Brooks,2008; Kosmatka et al.,2003; BS EN 13055,2002; Chandra & Bertsson 2002; ACI 213R-03,2003). It is also worth noting that research in the use of organic natural aggregates in the form of PKS has advanced in other Africa countries in the past few decades (Alengaram et al., 2008a; Olanipekun et al., 2006; Teo et al., 2006b; Mannan & Ganapathy, 2004; Basri et al., 1999). The main characteristics of lightweight aggregate is its high porosity which eventually results in a lower specific gravity. In recent years, due to the numerous advantages of the use of lightweight aggregate concrete in construction, there has been an increasing interest in the production and also investigation of properties of this material (Shafigh et al, 2011; Kan & Demirbog, 2009; Subasi, 2009; Kilic et al, 2009). Coarse aggregates increase the strength of concrete. Combined gradation determines the paste requirement for a working concrete since the amount of void required needs to be filled by the same amount of cement paste in a concrete mixture. The proper combined gradation of concrete saves the amount of cement and water paste in concrete and helps to improve the dimensional stability and durability of concrete.

2.7.2 Lightweight Aggregate Concrete (LWAC).

Lightweight concrete is not a new invention in concrete technology; it has been used since ancient times (Shafigh et al, 2010). EuroLightCon (1998) reported that LWAC is defined by many codes as concrete having an oven-dry density of less than 2000 kg/m^3 and can be produced within a range of 300 to 2000 kg/m^3. The use of LWAC permits greater design flexibility and substantial cost savings, reduced dead load, longer span, better fire ratings, smaller sections, smaller sizes of structural members, less reinforcing steel and reduced foundation costs (Chen & Liu,2005; Balendran et al,2002). The defining line between lightweight aggregate concrete (BS EN 13055-1, 2002) and normal weight aggregate concrete (BS 8110-1, 1997) is the average density and compressive strength limits. For lightweight aggregate concrete (LWAC) production the most popular aggregate input is lightweight aggregate (LWA) (Polat et al., 2010). Manufactured lightweight aggregates have been used to produce structural concrete in developed countries for many years. Available literature shows that structural LWAC with compressive strength of 25 MPa can be produced with adequate economic benefits (Lui, 2005). However, the use of LWA from natural raw materials such as clay, slate, shale etc and from industrial by-products such as fly ash, PKS and slag have not been fully explored in developing and underdeveloped countries in Africa (Alengaram et al,2008a; Lim,2007; Lui,2005). Lightweight aggregates are produced in a very wide range of densities varying from 50 kg/m^3 for expanded perlite to 1000 kg/m^3 for clinkers (Chanadra & Berntsson, 2002). With these aggregates and high range water reducers, it is possible to have LWAC of 80 MPa cube compressive strength (Lim, 2007). Considering the practical advantages of LWAC, it has become a vital structural material leading to the increasing demand for the material. From the Federation

Internationale de la Precontrainte manual of lightweight aggregate concrete (FIP,1998), LWAC has shown to have many advantages such as lower dead load, heat insulation capacity, anti-condensation properties, reduction in use of resources, reduced energy demand and quicker production potential. It is lighter than the conventional concrete with a dry density of about 300 kg/m^3 (Neville and Brooks, 2008; BS EN 13055, 2002; ASTM C330,1999 as cited in Acheampong (2015). Bai et al. (2004) produced LWAC with densities in the range of 1569 to 1960kg/m^3 and having a 28-day compressive strength in the range of 20 to 40MPa. LWC is used in many applications such as pre-stressed concrete, reinforced concrete and insulation works.

2.7.3 Properties of Lightweight Aggregate Concrete (LWAC)

Structural concrete is the most used construction material in all types of civil engineering works. According to Bamigboye et al, (2015) concrete is basically of three types: the lightweight with density weighing less than 1,920 kg/m^3, normal weight concrete which is most commonly adopted with density of about 2,400 kg/m^3 and heavy weight concrete with density above 2,800kg/m^3. The hardened properties of LWAC differ significantly from those of normal weight concrete, mainly attributed to high porosity of LWA which causes high water absorption rate and smaller modulus of elasticity of concrete. In recent years, development of lightweight foamed concrete (LWFC) with high compressive strength of 40 MPa and fresh density of 1600 kg/m^3 and above have been developed (Lim, 2007). The high strength LWAC is basically produced using low water to cement or cementitious materials ratio and air in the form of performed foam. Yasar et al, (2003) studied the strength properties of LWAC made with crushed basaltic pumice (Scoria) and fly ash. LWAC with average density 0f 1863 kg/m^3 was produced and it was concluded that Scoria lightweight can be used in the production of structural LWAC. It was possible to produce a LWAC with a compressive strength of 25 N/mm^{2}using fly ash. Kilic et al., (2009) examined the effect of Scoria and the pumice aggregate on the strengths and unit weights of LWAC. Different aggregate sizes were used in their study and found that with a density range of 1368 to 1997 kg/m^3, cylinder compressive strengths of 15.8 MPa to 44.1 MPa could be achieved. It was concluded that aggregate type influenced the unit weight, compressive strength and flexural tensile strength of corresponding concrete. The compressive strength of LWAC is determined by the characteristics of the lightweight aggregate, compared to the strength of normal weight concrete which depends on the characteristics of the paste. For a given set of cement and aggregates under the same conditions of curing and testing, the compressive strength of a concrete primarily depends on water/cement ratio, mix proportions, consistency and degree of compaction. Water-cement ratio is the most important parameter to determine the compressive strength of concrete, consistence and durability (Wazin et al., 2011; Adeagbo, 1999). The effect of water-cement ratio on compressive strength of concrete usually depends on the properties of the mix constituents: sands, gravels and cements. Water-cement ratio has the same effect on the strength of LWAC as on normal weight concrete. Good workability of concrete however, cannot be achieved with a water-cement ratio below 0.40 without the use of super plasticizer (Neville, 2006). Currently newly developed superplasticizers allow the use of low water-cement ratio in order to achieve very high strength concrete without loss of workability (Halit, 2008). The direct relationship between the compressive strength and the amount of superplasticizer only existed up to an optimum limit of 1%. Beyond this limit, increase in the dosage of superplasticizer reduced the compressive strength of the strength (Alsadey, 2012). Superplasticizers are used to improved workability of fresh concrete and to produce high performance concrete. The effect of superplasticizers on LWAC is similar to that of using them in normal weight concrete (Popovic, 1992).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

All the materials used in this study are locally available within the Ashanti Region environment.

3.1.1 Binder

Ordinary Portland cement class 32.5R manufactured by Ghacem at Tema in the Greater Accra which meets the requirements of the BS EN 197-1(2000) was used in the LWC production. It is marketed in most cement shops within the Kumasi Metropolis. The cement was taken to the laboratory in 50kg bags and was carefully kept away from dampness to avoid lumps.

3.1.2. Fine Aggregate

Fine river sand was sourced from Adom Superblock Construction Site in Kumasi Metropolis for experimental purpose in this study, conforming to BS EN 12620:2002.

3.1.3 Coarse Aggregate

The crushed PKS was used as coarse aggregate up to 12mm (all particle sizes inclusive) and using different specific PKS sizes (retained on 6mm, 8mm, 10mm and 12mm sieve sizes for the experimental test in the mix). The PKS was obtained in broken form from Asante- Mampong Newtown. The shells were loaded in sacks and transported to the laboratory. Figure 3.1 shows samples of the various specific sizes of PKS used in this experimental study.

Figure 3.1 The various specific sizes of PKS

3.1.4. Water

Clean tap water was sourced from the construction laboratory of the University of Education, Winneba-Kumasi Campus supplied by Ghana Water Company Limited. It conformed to the specification of ASTM C94/94M (2004) and BS EN1008:2002.

3.2. Equipment

The following equipment were used in this study:

- 100mm×100mm×100mm cube steel moulds.
- 100mm×100mm×500mm beam steel moulds.
- Compression testing machine
- Universal concrete strength testing machine.

- Other apparatus including: shovel/spade, trowel, scoop, jute sack, head pan, vibrating table, electronic weighing balance, grading sieves, caliper, steel rule and level surface (tray).

3.3. Methods

3.3.1. Experimental Program

The PKS was washed, air-dried and sieved. For the PKS as coarse aggregates, particles retained on 6mm, 8mm, 10mm and 12mm sieve were used for the experimental study while particles passing through the 6mm were discarded. This study involved experimental investigation using four different specified grade sizes including the mixed up which made of all grades size of PKS together in equal proportions. A constant mix ratio of 1:2:3 with a water-cement ratio of 0.6 was adopted. The aggregates were pre-soaked for 24 hours in potable water prior to mixing and were in saturated surface dry condition during mixing to prevent absorption of mixing water. Studies have shown that for agricultural based wood materials used in concrete production, the pre-treatment is important to ensure that extractable materials do not upset the hardening qualities of the cement. According to Paramasivam & Loke (1980) experiments have shown that most kinds of wood based materials can be improved substantially by soaking and washing with water before mixing. This process was adopted in this experimental work. The compressive strength of hardened concrete was determined after 7,14, 21 and 28 days of curing. Then also flexural strength was carried out on the hardened concrete beams using the Universal concrete strength testing machine at the end of each curing age. Five different mixes of concrete were produced using different specific sizes at various percentages and concrete samples were labelled as follows:

Sample A = 6mm PKS replacement of coarse aggregate (100%)

Sample B= 8mm PKS replacement of coarse aggregate (100%)

Sample C = 10mm PKS replacement of coarse aggregate (100%)

Sample D = 12mm PKS replacement of coarse aggregate (100%)

Sample E= 6mm (25%) + 8mm (25%) + 10mm (25%) + 12mm (25%) PKS replacement of coarse aggregate.

3.3.2 Batching, Mixing and Curing of Palm Kernel Shell Concrete (PKSC)

The batching by weight method was used. The mixing of concrete constituents was done with a pan mixer with mix ratio 1:2:3 and water-cement ratio of 0.6 for all mixes. The Palm kernel shell was pre-soaked in potable water for 24 hours to achieve saturation before mixing. Firstly, the sand and cement were batched and poured onto the pan mixer and dry mixed for 1min. Secondly, PKS was poured on the mixture and mixed for 1min. It was ensured that the materials were uniformly mixed before the water was added. After this activity, the fresh concrete mix was placed into cube and beam steel moulds, then vibrating on table to eliminate air bubbles in the mixture. The specimens were de-moulded approximately 24 hours after casting and they were cured under wet jute sacks at laboratory temperature of 27 ± 2ºC until the age of testing for compressive and flexural strength. All the specimen cubes and beams were in the jute sack for a total of 28 curing days in intervals of 7 days. During this period the specimens were sprinkled with water at every 24 hours until the curing day reached for testing. Three replicates were prepared for specimens at each curing age for each mix including mixed up of PKS content to product PKSC. A total of 120 specimens, 60 specimens each for cubes and beams were produced for compressive and flexural strength test respectively. The curing was done in accordance with British Standard BS EN 12390-2:2019. Figure 3a shows the specimens of concrete cubes and beams, then also Figure 3b shows the curing process of the specimens.

Figure 3.2a: Concrete cubes and beams

Figure 3.2b: Curing of specimens

CHAPTER FOUR

4.1 Introduction

The physical properties tests conducted include sieve analysis, bulk density, water absorption and specific gravity to describe the aggregate including the testing of dry density, compressive and flexural strength of the specimens.

4.1.1 Sieve Analysis of Aggregate (Grading)

The grading of an aggregate is defined as the frequency of distribution of particle size of a particular aggregate. The sieve analysis was done in accordance with BS 812; Part 103, 1990. Normally the sieve analysis uses table with columns which includes: Sieve size, Mass retained on the sieve, the Percentage of aggregate retained on the sieve and Percentage of aggregate passing each sieve. Firstly, the particles of the aggregate were sieved with the various standard sieves for the test. After that sieving process the various portions retained in the various sieves were weighed using the electronic scale. The weighed values are called the Mass retained on the sieve for each sieve then the listed formulas in the below are used to calculate for the Percentage Retained and Percentage Passing each sieve.

Calculation of Percentage Retained on Sieve

The following formula was used to calculate the percentage of aggregate retained on the sieve

Percentage Retained = $\frac{Mass\ of\ aggregate\ Retained\ on\ Sieve}{Total\ Mass\ of\ Sample} x100$

Calculation of Percentage of aggregate passing each Sieve

The values obtained in the above captioned percentage of aggregate retained were used to calculate the percentage passing each sieve. The calculation started at the top by deducting the cumulative value from 100. The value 100 in this case is once again the percentage value.

4.1.2 Bulk density of the Aggregate

Bulk density of the sample is simply its mass divided by its volume. It can be calculated directly by measuring the mass of a sample and dividing it by the volume of the mould. The test was carried out on the samples with PKS aggregate which conformed to ASTM C29/C29M (2003) and the formula used to calculate the bulk density is shown below:

Bulk density = $\frac{weight\ of\ sample\ (w3)}{volume\ of\ mould\ (v)}$

Where W_1= Weight of empty mould (g)

W_2 = Weight of mould + Sample (g)

W_3 = Weight of Sample ($W_3 = W_2 - W_1$)

4.1.3 Water Absorption Test

According to BS EN 1097-6(2000), water absorption of an aggregate is defined as the increase in the weight of the aggregate due to water being absorbed into the pores of the material during the prescribed time, but not including the water adhered to the surface of the aggregate. Below was procedure used to determine the water absorption values for fine and coarse aggregate in this study. Firstly, about 1000g of aggregate sample was taken, washed to remove fines and other impurities from them. The clean aggregate was then immersed in a glass bottle containing water at a constant temperature of 26 ^{0}C for a period of 24 hours. The aggregates were weighed while suspended in water and then removed from water and dried with dry absorbent cloth, the surface dried aggregates were also weighed. The aggregate was placed in a shallow tray and heated to 110 ±5 ^{0}C in the oven for 24 hours. The aggregate was removed, allowed it to cool and weighed. The water absorption test was done in accordance with BS EN 1097-6(2013), the equation provided was used to calculate for the absorption percentage values.

Water absorption = $\frac{W2-W1}{W1} x100$

$Where\ W1 = weight\ of\ oven\ dry\ aggregates\ in\ air$

$W2 = weight\ of\ saturated\ aggregates\ in\ air$

$W3 = weight\ of\ water\ absorbed\ (w2 - w1)$

4.1.4 Specific Gravity of Aggregate

Specific gravity can be defined as the ratio to the weight of given volume of aggregates to the weight of equal volume of water. Specific gravity determination was done according to ASTM C127-07(2007), a standard that was used to determine the specific gravity of materials. This standard was employed to determine specific gravity of sand and the various sizes of PKS by using pycnometer method. The procedure used for specific gravity determination of aggregate was described below;

A clean dry pycnometer vessel was taken, and its empty weight was determined. 1000g of clean sample was taken into pycnometer vessel and weighed. Water temperature of 26 ^{0}C was filled up in the pycnometer vessel with aggregate sample, immediately after immersion the entrapped air was removed from the sample by shaking pycnometer vessel, placing a finger on the hole at the top of the sealed pycnometer. Now the pycnometer vessel was completely filled up with water and after confirmed that there was no more entrapped air in it, it was weighed.

The contents of the pycnometer vessel was discharged and cleaned. Water was filled up to the top of the pycnometer vessel, without any entrapped air, it was then weighed. The pycnometer vessel was filled up of aggregate to the one-third of the capacity of vessel and completely immersed in water for a period of 24 hours. The aggregates in the pycnometer vessel were weighed while suspended in water, at a temperature of 26 ^{0}C. The aggregates were removed from water and dried with dry absorbent cloth. The aggregates were then placed in a shallow tray and heated in an oven at temperature of 110 ^{0}C±5 for 24 hours. The aggregates were then taken from the oven, allowed to cool and weighed. The equation provided below was used to calculate for specific gravity of aggregate values.

Specific gravity = $\frac{(w2-w1)}{(w4-w1)-(w3-w2)}$

$Where\ W1g = Weight\ of\ pycnometer\ in\ air$

$W2g = Weight\ of\ aggregate\ and\ pycnometer$

$W3g = Weight\ of\ aggregate\ and\ pycnometer\ and\ water$

$W4g = Weight\ of\ pycnometer\ and\ water$

4.2 Testing of Specimen

4.2.1 Dry Density Test

The density of the hardened samples was determined based on ASTM C 1745/1745M (2012) using the volumetric method. Density is defined as the mass of a unit volume of the solid (concrete). The sample was weighed using the electronic weighing balance. The sample was taken by measuring the length, breath and height. The density was calculated using the formula stated below and it is measured in kilogram per cubic meter (kg/m^3).

Density = $\frac{Mass\ (M)}{Volume\ (v)}$

4.2.2 Compressive Strength Test

Test for compressive strength was carried out on concrete cube. The compression testing machine was used for testing compressive strength of concrete specimen. The specimens were removed from the sack after specified curing time. The machine bearing surface was cleaned and the specimen was placed in the machine in such a manner that the load was applied to the cube specimen. The specimen was aligned centrally on the base plate of the machine and the moveable portion was rotated gently by hand so that it touched the top surface of the specimen. Then load was applied gradually until the specimen failed and the maximum load was recorded. Figure 4.1 shows the testing of concrete cube for compressive strength which conformed to BS EN12390-3(2019) and it is measured in N/mm^2 using this equation:

Compressive strength = Load in N/ Area in mm^2

Compressive strength = N/mm^2.

Figure 4.1 Testing of concrete cube

4.2.3 Flexural Strength Test

The universal strength testing machine was used to test the flexural strength of concrete specimen. The beam mould size was 100mm×100mm×500mm. The three-point load test was used in determining the flexural strength of hardened concrete specimens. Figure 3.3 shows the testing of concrete beam and the flexural strength was tested based on ASTM C78 (2004) or BS EN 12390:4(2019). It was measured in terms of the modulus of rupture computed using equation:

$$MR= \frac{3PL}{2bd^2}$$

Where MR=Modulus of Rupture in Mega Pascal (MPa)

P= Load at fracture in N

L= Span length in mm

b= Average width of the specimen at the fracture in mm

d= Average depth of the specimen at the fracture in mm.

Figure 4.2 Testing of the concrete beam.

4.2.4 Microscopic Test

The microstructure of concrete specimen was analyzed using Scanning Electron Microscope (SEM) which help to visualize the microstructure of the hydrated cement paste. Analysis of microstructure of concrete was the modern approach to examine the mineral composition in the concrete. SEM instrument also helped to show the surface texture and porous nature of PKS aggregates. Specimen preparation was important in any microscopic technique with proper preparation methods facilitating examination and interpretation of microstructural features. SEM analysis using backscattered electron and X-ray imaged required a highly polished surface for optimum imaging. Rough- texture surfaces, including those produced using only saw-cutting diminish the image quality by reducing contrast and loss of feature definition. An epoxy resin was used to permeate the specimen's pore system or to encase powder particles. The specimens were then cut or ground to expose a fresh surface and that surface was then polished using a series of successively finer grades of diamond paste. This polishing stage was necessary to remove cutting and grinding damage, and to expose an unaltered cross section of the specimen's microstructure. Through Energy Dispersive Spectroscopy (EDS) was used to find out the chemical composition of PKSC specimens. The backscattered electron (top) and X-ray (bottom) of the specimen showed good definition of constituents.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Introduction

This chapter presents the analysis of the results as discussed in the chapter four. It presents the physical properties of PKS particles, dry density of specimen, the compressive and flexural strength of PKSC including the microscopy nature of the PKS particles and PKSC including the chemical composition of the specimens.

5.2 Particle Size Distribution.

Table 5.1 is the sieve analysis carried out on the fine aggregate in accordance with the BS 812; Part 103, 1990 and ASTM C 136-01 (2001). Table 4.1 shows that the river sand used for the experiment was well graded with a maximum size of 2.36mm. The coarse aggregate specific sizes of PKS used were 6mm, 8mm, 10mm and 12mm.

Table 5.1 Sieve Analysis (Grading) of Sand

Sieves (mm)	Mass Retained (g)	Retained (%)	Passing (%)
5	-	0	100
2.36	13	1.2	98.8
1.18	236	21.9	76.9
600um	252	23.4	53.5
300um	234	21.7	31.8
150um	144	13.3	18.5
Pan	200	18.5	0
Total	**1079**	**100**	

5.3 Specific Gravity

Table 5.2 reveals the specific gravity or relative density of PKS as coarse aggregate used in this study. According to ACI Education Bulletin EI-07 (2007) the specific gravity of aggregate ranges from 2.30 to 2.90. The specific gravity for sand was 2.39 and the crushed PKS specific gravity values were 1.30, 1.26, 1.24, 1.29 and 1.26 for the various sizes 6mm, 8mm, 10mm, 12mm and mixed up respectively. The specific gravity values obtained for various sizes of PKS were within the ranged stated by Okpala (1990) which said that PKS has specific gravity ranged from 1.17 to 1.37. The results of specific gravity of fine aggregate shown in Table 5.2 is within the acceptable limits while that of PKS is below the limit (2.30 to 2.9) and it implies that PKS is a lightweight aggregate. Then also according to (Neville & Brooks, 2010) majority of natural aggregates have a specific gravity between the values obtained for various specific sizes of PKS fall below the range of specific gravity for normal weight aggregates. Due to that the PKS can be classified as lightweight aggregates. In Table 5.2, the various specific sizes of PKS met the maximum requirement for loose bulk density and compacted bulk density of lightweight aggregate, which are 880 kg/m^3(ASTM C330-04,2004) and 1000 kg/m^3(Prusty & Patro,2015) respectively. From Table 4.2, lower bulk density was obtained for PKS size 10mm as result of the lower specific gravity.

Table 5.2 Properties for Aggregate

Physical Properties	**Palm Kernel Shell**					**Sand**
Size (mm)	6	8	10	12	Mixed up	0 – 2.36
Specific Gravity	1.30	1.26	1.24	1.29	1.26	2.39
Bulk Density. (kg/m^3)	634	611	580	591	633	1509
Shell Thickness (mm)	2.0	3.0	3.9	4.0	-	-
Water Absorption for (24h).	21%	15%	12%	14%	11.6%	0.56%

The water absorption values obtained were found to be within range of absorption capacity of lightweight aggregates which have been put at 5%-25% (Shafigh et al., 2010; Newman & Choo, 2003; Concrete Society of UK, 1987). It was reasonable to conclude that the shells absorb very little amount of mixing water during concrete production because of pre-soaking of the PKS aggregates. Then also it was observed that PKS size of 6mm has a high absorption value, aggregates having more absorption are more porous in nature. The low specific gravity of PKS size 10mm shows that it is impervious lightweight aggregate and its absorption value was low as compared with various specific of PKS sizes. The water absorption of the aggregate differs as shown in the Table 5 .2, PKS sizes 6mm should has required a small amount of water to achieve the water and cement proportion than the rest of the sizes. The fact that same amount of water was used in the mixes suggest that larger amount of water was actually employed in the PKS concrete mixes with the size 6mm.

5.4 Density for Palm Kernel Shell Concrete (PKSC)

A Study done by Acheampong et al. (2013) revealed that normal weight concrete cubes cracked exploded under compression testing machine. However, in this study the PKSC experienced gradual cracked explosively without any sound. This could be attributed to the relatively lower density of PKSC as it plays role in the reduction of dead load. The density of PKSC at 7, 14,21 and 28days of curing are presented in Table 5.3 and Figure 5.1.

Table 5.3 Average Dry Density of Palm Kernel Shell Concrete (kg/m³).

Curing	Sample sizes				
days	6mm	8mm	10mm	12mm	Mixed
7	1449.267	1511	1625.40	1681	1616.67
14	1506.67	1514	1696.73	1690	1623.53
21	1447.27	1495	1714.27	1667	1602.87
28	1509.73	1497	1624.13	1685	1610.47

The results obtained from these experimental tests are represented in graphical forms as shown in Figure 5.1.

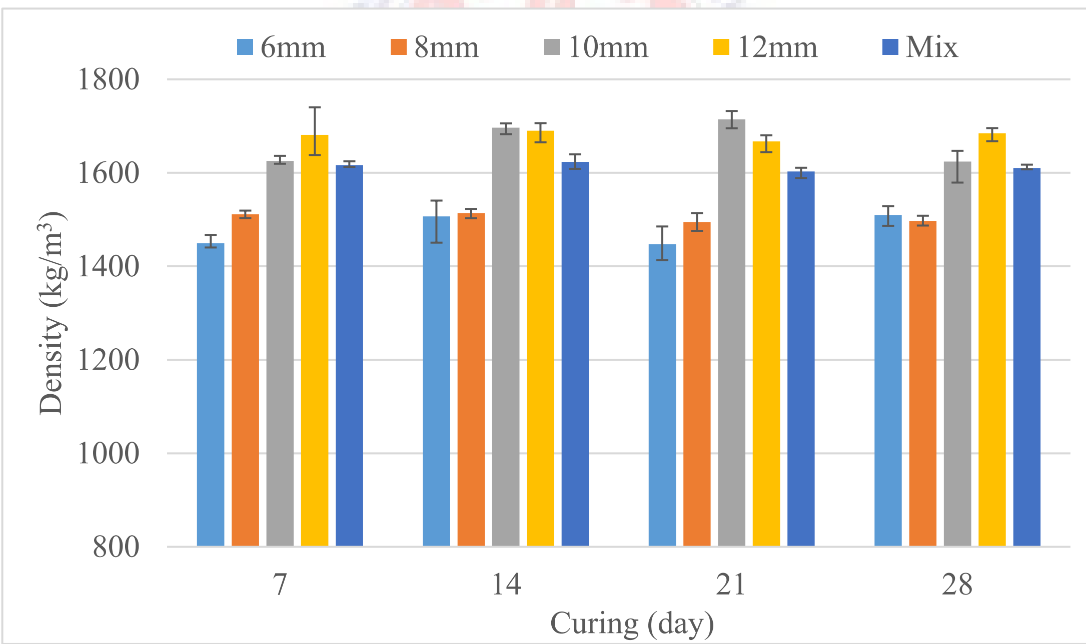


Figure 5.1: Average Dry Density Result

The dry density of the samples was evaluated at 7 days,14 days,21 days and 28 days. Average dry densities of concrete samples are summarized in Table 5.3. Table 5.3 indicates minimum and maximum concrete densities of 1447.27 kg/m^3 and 1714.27 kg/m^3 at 6mm and 10mm PKS replacement respectively. The minimum and maximum densities were observed at 21 days of curing time, a denser concrete generally provides higher strength and fewer amount of voids and porosity. Conversely, the range for density of structural lightweight concrete is 1440-1850kg/m^3(ACI 213R-87,2003). From the results of Table 4.3 and Figure 4.1, the density of 1509.73kg/ m^3,1497kg/ m^3,1624.13kg/ m^3,1685kg/m^3 and 1610.47kg/m^3 respectively recorded for full replacement at curing age of 28 days falls within the range for structural LWC and suggests that PKS can be used as structural lightweight concrete (ASTM C330,2004). ASTM C330-04(2004) defines the density of structural lightweight concrete as concrete having dry density not exceed 1840kg/ m^3. The values obtained for this study were the exact numerical value of 28 days- dry bulk density of PKSC which did not exceeding 1840kgm^{-3}. The dry densities of PKSC mixes are less than 2000kg/ m^3 in this study which was aligned with the values stated in the literature review for LWC. The PKS obtained from Palm nut can be classified as organic lightweight aggregate. Test on the concrete made with this material as coarse aggregate, show a density range of 1447.27 to 1714.27kg/ m^3 for all curing age which classifies it as LWC.

5.5 Compressive Strength Test

The compressive strength of concrete is one of the most important and useful properties of concrete. In most structural application, concrete is used primarily to resist compressive stresses. The compressive strength was calculated from the failure load divided by the cross sectional area resisting the load. The compressive strength test conformed to BS EN 12390-3(2002) and the average compressive strength test result is shown in Table 5.4 and Figure 5.2.

Table 5.4: Average Compressive Strength for Palm Kernel Shell Concrete (N/mm^2)

	Sample sizes				
Curing days	6mm	8mm	10mm	12mm	Mixed
7	3.533	3.133	3.400	5.567	4.700
14	3.700	3.300	3.533	6.200	4.933
21	4.067	3.400	3.833	6.267	5.033
28	4.100	3.833	5.167	6.500	5.767

The results obtained from these experimental tests are represented in graphical forms as shown in Figure 5.2.

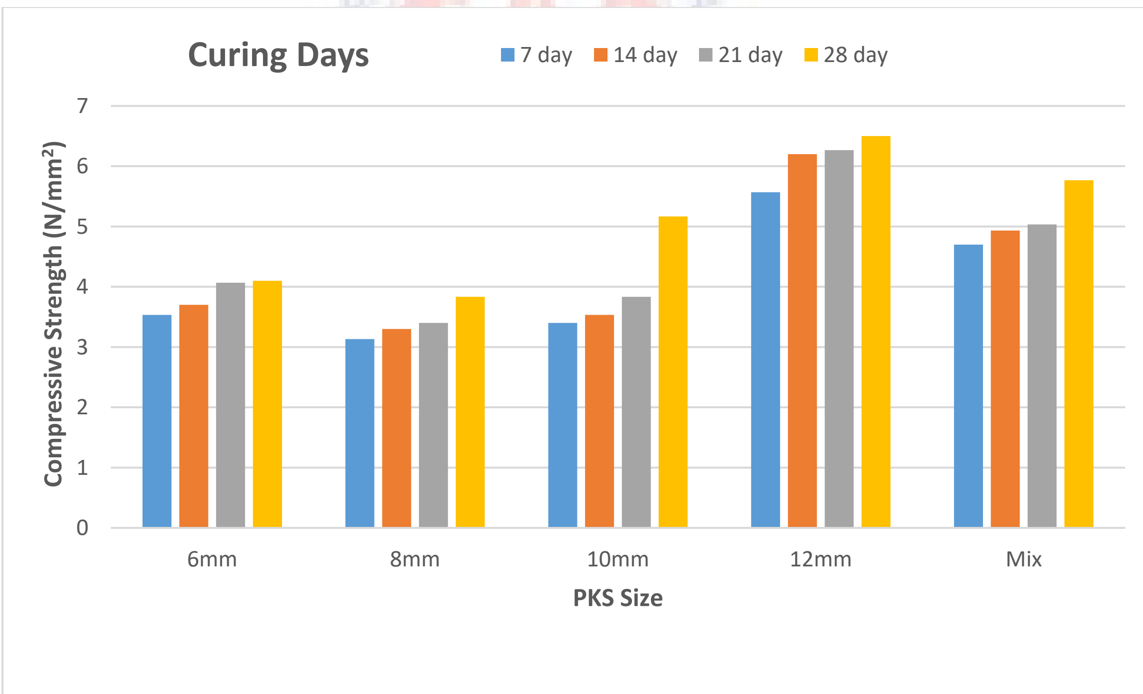


Figure 5.2: Compressive Strength Result

Figure 4.2 shows that the compressive strength increases with curing age from 7 to 28 days for all the sizes of coarse aggregates (PKS) like normal concrete. Neville (1995) concluded that, the understanding of the strength-time relation is of importance when a structure is to be put into use and expose to full loading, at a later age. The compressive strength of the samples increases as the curing age increases. For example, the aggregate sizes of 6mm,8mm,10mm,12mm and Mixed PKS content, at 7 day recorded an average compressive strength of 3.533 N/mm^2, 3.133 N/mm^2,3.400 N/mm^2,5.567 N/mm^2 and 4.700 N/mm^2 respectively. The average compressive strength for 28-day were 4.100N/mm^2, 3.833N/mm^2,5.167N/mm^2,6.500N/mm^2 and 5.767N/mm^2 for aggregate sizes of 6mm, 8mm, 10mm, 12mm and Mixed PKS content respectively. The corresponding percentage increase in strength between consecutive curing ages thus (7 and 28 day) were 13.83%, 18.26%, 34.20%, 14.35%, 18.50% for 6mm,8mm,10mm,12mm and Mixed PKS content respectively. 8mm PKS aggregate size recorded the lowest average compressive strength for all the curing age (7,14,21 and 28 days) and 12mm PKS aggregate size recorded the highest average compressive strength (7,14,21 and 28 days) as shown in Figure 5.2. From the results presented in Table 5.4, it can be noted that for every class of PKS size, the 28-day average compressive strength increased to attain a maximum value before it decreased depending on the shell size in the concrete mix. This trend appeared to be similar irrespective of the PKS size, there were some slight variations in the strength. The results indicated that compressive strength increases progressively with the maximum aggregate size 12mm giving the highest strength of 6.500 N/mm^2 for 28 days of curing in Table 5.4 while 8mm shell size recorded the lowest value of the 7-day average compressive strength of 3.133 N/mm^2. Raheem et al. (2008) research work reported that the strength of the shell also plays a significant role in the strength of the concrete. The performance of 12mm PKS size concrete can be attributed to the strength of the larger size shells and Mixed up concrete was next highest of compressive strength which may be due to the smaller size shells packed the voids. Because the voids ultimately influenced the strength, fewer amount of voids in concrete it becomes less permeable to water and soluble elements. When more water can be found in concrete, it has significant effect on the compressive strength. Conversely, the results of the mixed up concrete was higher than other PKS sizes except 12mm, which may be due to the smaller size of PKS was able to fit into the pores and thus decreased the void content created by the larger ones giving a more compact concrete. The low compressive strength of PKSC could be attributed to the elongated nature, smoother texture and convex shape of PKS which results in relatively weaker bond between the PKS(s) and cement paste. The mode of reduced strength of the PKSC with PKS suggests that, the strength of PKS depends on the strength of the mortar and the interfacial bond between the PKS and cement matrix. Table 5.2 shows higher water absorption capacity values for the various PKS sizes which may also have effect on the compressive strength and stiffness of the PKSC in this study.

5.6 Flexural Strength Test

The trend of the test results of the flexural strength is somewhat similar to the compressive strength test results. Table 5.5 and Figure 5.3 present the effect of aggregate size at 7,14,21 and 28 curing days on the flexural strength of PKS concrete.

Table 5.5 Average Flexural Strength for Palm Kernel Shell Concrete (N/mm^2)

	Sample sizes				
Curing days	**6mm**	**8mm**	**10mm**	**12mm**	**Mixed**
7	0.231	0.341	1.263	1.423	0.966
14	0.341	0.581	1.403	1.754	1.080
21	0.662	0.817	1.505	1.959	1.116
28	0.836	0.936	1.761	2.185	1.467

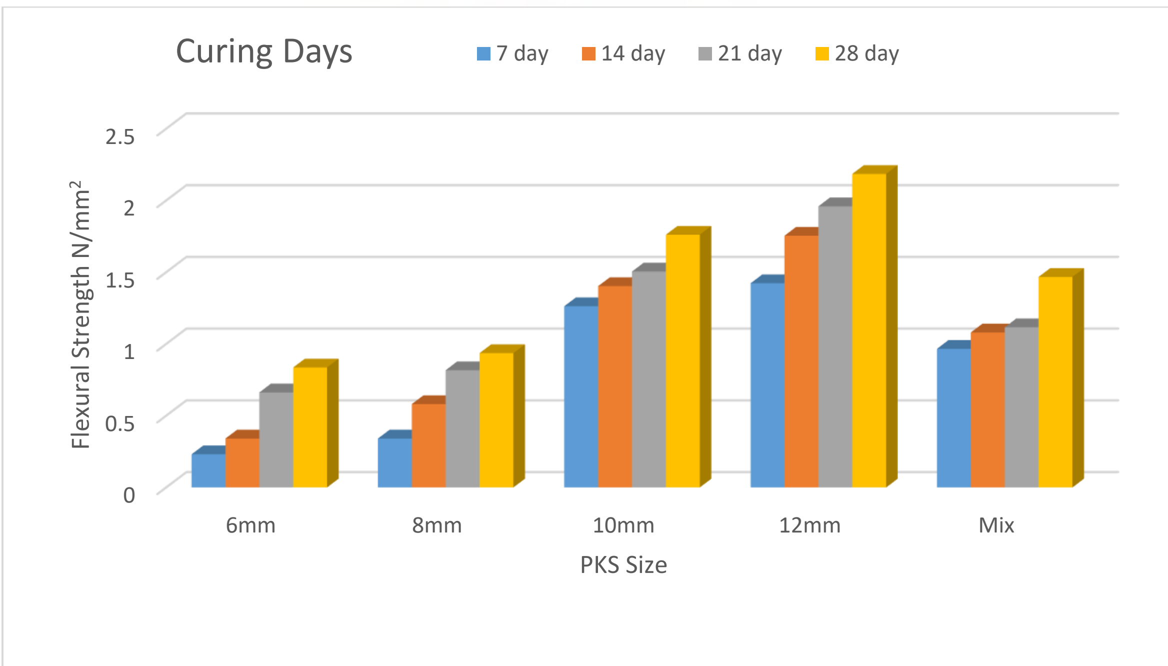


Figure 5.3: Flexural Strength Result

The flexural strength of PKSC was tested at the age of 7,14,21 and 28 days. Table 5.5 shows the average flexural strength of PKSC in this study, which was indicated that aggregate size 12mm possess higher strength values in comparison to the other sizes. This signifies that, the larger PKS sizes present in the concrete mix obtained higher flexural strength values as shown in figure 5.3. Research work done, indicated that a poor bond between the PKS and the cement matrix that resulted in bond failure. (Shafigh et al., 2011; Neville,1996). This contributed to lower mechanical properties in PKSC in this experimental study, the bond failure may be attributed to the smooth and convex surface of PKS. Table 5.4 and 5.5 indicate the strength values in compressive and flexural strength which were low, may be due to bond failure, because the interfacial zone between the aggregate and the paste is weak. Thus, apart from lower PKS stiffness, weaker bond can be regarded as another factor that influences the PKSC mechanical properties. Figure 5.3 shows the strength values and the variation in flexural between the various coarse aggregate sizes were mainly due to the lower strength and stiffness of the PKS. The presence of high volume of pores in PKS causing its high water absorption may weaken the particle strength and stiffness.

5.7 Statistical Analysis and Interpretation

According to SAS (2012), the effect of aggregate size of PKS and curing age (called independent variables) on the compressive strength (called dependable variable) was statistically analyzed using Sigma Plot (Version 12) Statistical Analysis Software.

Table 5.6: Compressive Strength Descriptive Statistics (28-days).

Treatment Name	N	Mean	Std Dev	SEM
6mm	3	4.100	0.400	0.231
8mm	3	3.833	0.208	0.120
10mm	3	5.167	0.513	0.296
12mm	3	6.500	1.007	0.581
Mix	3	5.767	0.833	0.481

Table 5.6 shows the descriptive statistics of different sizes (6mm,8mm,10mm,12mm and Mix) of PKS as coarse aggregate in light weight concrete for 28-day compressive strength analysis. The table also shows values of mean, standard deviation and standard error. The mean values for 6mm,8mm,10mm,12mm and Mix PKS were 4.100, 3.833, 5.167, 6.500 and 5.767N/mm^2 respectively. The maximum strength was obtained for coarse aggregate size 12mm with a mean value of 6.500 and 8mm size recorded the lowest mean value of 3.833. This indicates that the strength for the various sizes of PKS are significantly different, hence from the table 5.6 difference treatment name were used namely; 6mm, 8mm, 10mm, 12mm and Mix for this statistics analysis.

5.7.1 One-way ANOVA for Compressive Strength Test (28-day)

The influence of PKS sizes and curing age (independent variables) on the compressive strength (dependent variable) was analyzed statistically. (Okafor et al.,1996; SAS,2012). Table 5.7 indicates the output of the ANOVA of the compressive strength test. The analysis was to determine which of the factors considered had significant effect on the compressive strength of the concrete. The results of the statistical analysis as shown in Table 5.7, indicated that the independent factors and their interactions had significant effects on the compressive strength of the concrete at 95% confidence level (p=0.05). This indicates that whenever any of the factors is varied, the compressive strength of the concrete changes and degree of the variation is proportional to the magnitude of the change. The p-value of 0.008 was found to be less than the alpha level of 0.05. Statistically, the effect of PKS aggregate size on the compressive strength for the various aggregate sizes was found to be significant.

Table 5.7: One-way ANOVA Test Result

Source of Variation	DF	SS	MS	F	P
Between Subjects	2	0.0160	0.008		
Between Treatments	4	16.309	4.077		0.008
Residual	8	4.331	0.541		
Total	14	20.656			

Table 5.8: All Pairwise Multiple Comparison Procedures (Holm-Sidak method)

Comparison	Diff of Means	T	P	P<0.050
12mm vs. 8mm	2.433	4.051	0.036	Yes
12mm vs. 10mm	2.433	4.051	0.033	Yes
12mm vs. 6mm	2.167	3.607	0.054	No
Mix vs. 8mm	1.933	3.218	0.083	No
Mix vs. 10mm	1.933	3.218	0.071	No
Mix vs. 6mm	1.667	2.774	0.115	No
12mm vs. Mix	0.500	0.832	0.894	No
6mm vs. 10mm	0.267	0.444	0.964	No
6mm vs. 8mm	0.267	0.444	0.890	No
8mm vs. 10mm	0.000	0.000	1.000	No

Table 5.8 reveals All Pairwise Multiple Comparison Procedures (Holm-Sidak method). It shows comparison amongst the various PKS sizes used in the experiment in relation to compressive strength. The comparison between 12mm and 8mm PKS sizes recorded means difference of 2.433 and p-value of 0.036 which is less than the alpha value of 0.050. This indicates that the difference in mean is statistically significant between PKS size 12mm and 8mm. 12mm vs.10mm recorded 2.433 as their means difference which was same as that of 12mm vs 8mm. The difference of means for 12mm vs 10mm observed a p-value of 0.033 which is less than the alpha value of 0.050, indicating that the means difference obtained was statistically significant. The means difference recorded for 12mm vs. 6mm, Mix vs. 8mm, Mix vs. 10mm, Mix vs. 6mm, 12mm vs. Mix, 6mm vs. 10mm, 6mm vs. 8mm and 8mm vs. 10mm were 2.167,1.933,1.933,1.667,0.500,0.267,0.267 and 0.000 respectively. As shown in the Table 4.8 the means difference of these PKS sizes recorded a P-value greater than the Alpha value of 0.050. This is an indication that their means differences recorded are not statistically significant (insignificant). The results of the statistical analysis as shown in Table 4.8 indicated that the aggregate sizes and their interactions had significant effect on the compressive strength of PKSC at 95% confidence level ($p<0.050$). From the table when matching the aggregate sizes, all the sizes of PKS are insignificant except 12mm vs.8mm and 12mm vs. 10mm which are significantly different. They are insignificant because of their P-values obtained were greater than Alpha value of 0.050.

5.7.2 Flexural Strength Descriptive Statistics (28-day)

Table 5.9 shows the descriptive statistics of different sizes 6mm, 8mm, 10mm, 12mm and Mix of PKS as coarse aggregate in light weight concrete for 28-day flexural strength analysis. The table shows the values of mean, standard deviation and standard error. The mean values for 6mm, 8mm, 10mm, 12mm and Mix PKS were 0.838,0.936,1.762,2.185 and 1.467N/mm^2 respectively. The shell size 12mm recorded the highest mean of 2.185 and 6mm PKS size recorded the lowest mean value of 0.838.

Table 5.9: Flexural strength Descriptive Statistics

Treatment Name	N	Missing	Mean	Std Dev	SEM
6mm	3	0	0.838	0.0646	0.0373
8mm	3	0	0.936	0.0275	0.0159
10mm	3	0	1.762	0.0570	0.0329
12mm	3	0	2.185	0.0976	0.0563
Mix	3	0	1.467	0.222	0.128

5.7.3 One –way ANOVA for Flexural Strength Test

The influence of aggregate size and curing age (independent variables) on the Flexural strength (dependent variable) was statistically analyzed using Statistical Analysis. The output of the Analysis of Variance (ANOVA) of the compressive strength test is presented in Table 5.10. Statistically, the effect of PKS aggregate size on the flexural strength for the various aggregate sizes was determined and analysis showed that there was a significant effect. The results of the statistical analysis as shown in Table 5.10, indicated that the independent factors and their interactions had significant effect on the flexural strength at 95% confidence level (p=0.05). This shows that whenever any of the factors is varied, the flexural strength of the PKSC changes and degree of the variation is proportional to the magnitude of the change. The p-value of 0.001 was found to be less than the alpha level of 0.05.

Table 5.10: One-way ANOVA Test Result

Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Between Subjects	2	0.0351	0.0176		
Between Treatments	4	3.827	0.957	77.211	<0.001
Residual	8	0.0991	0.0124		
Total	**14**	**3.962**			

Table 5.11 shows all Pairwise Multiple Comparison Procedures (Holm-Sidak method) and the comparison amongst the various PKS sizes used in the experiment with respect to flexural strength. The comparison between 12mm and 6mm PKS sizes recorded the highest mean difference of 1.347 and p-value of 0.001 which is less than the alpha value of 0.050. This indicates that the difference in mean is statistically significant between the both aggregate sizes. 12mm vs.8mm recorded 1.249 as their means difference with a p-value of

0.001 which less than the alpha value of 0.050. 10mm vs.6mm, 10mm vs.8mm, 12mm vs. Mix, Mix vs. 6mm with means differences of 0.924, 0.826, 0.718 and 0.629 respectively with a common p-value of 0.001 which is less than the alpha value of 0.050. Mix and 8mm, 12mm vs. 10mm, 10mm vs. Mix recorded their means difference values 0.531, 0.423, 0.295 with a p-value 0.002, 0.005 and 0.023 respectively and their p-values are less than the alpha value of 0.001. Table 5.11 reveals that all the p-values which are less than the alpha-value of 0.05 are statistically significantly different while alpha-value greater than 0.05 means it is not statistically significant difference between the aggregate sizes (insignificant).

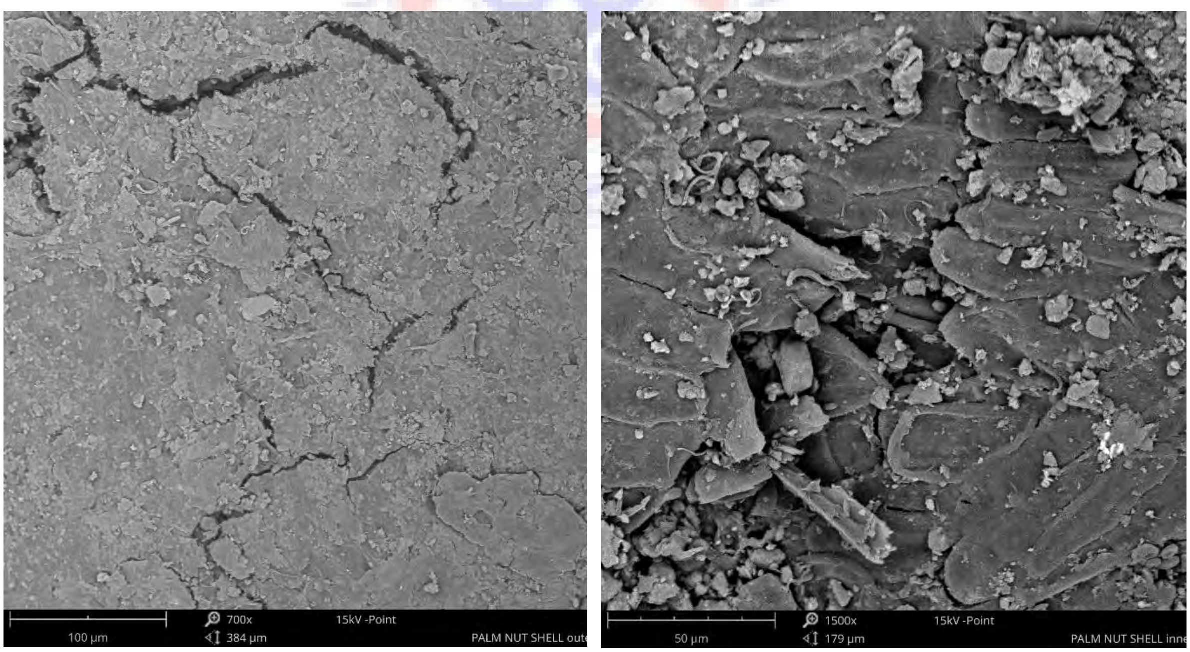
Table 5.11: All Pairwise Multiple Comparison Procedures (Holm-Sidak method)

Comparison	Diff of Means	T	P	P<0.050
12mm vs. 6mm	1.347	14.819	<0.001	Yes
12mm vs. 8mm	1.249	13.741	<0.001	Yes
10mm vs. 6mm	0.924	10.166	<0.001	Yes
10mm vs. 8mm	0.826	9.087	<0.001	Yes
12mm vs. Mix	0.718	7.899	<0.001	Yes
Mix vs. 6mm	0.629	6.920	<0.001	Yes
Mix vs. 8mm	0.531	5.842	0.002	Yes
12mm vs. 10mm	0.423	4.654	0.005	Yes
10mm vs. Mix	0.295	3.245	0.023	Yes
8mm vs. 6mm	0.0980	1.078	0.312	No

5.8. SEM (Scanning Electron Microscopy) Analysis of PKS

The surface morphology of PKS was examined by using SEM instrument. Figure 5.4 shows the micrograph of the raw PKS analysis at the magnification of 700x (outer surface) and 1500x (inner surface) which exhibits the surface of PKS in (a) and (b) respectively. The surface consisted of botanical pores which seemed to have irregular arrangement and some of these pores were unusually large. These pores would provide a template for the development of macro pore in the resulting chars (Jia & Lua,2008). The SEM images shown in Figures 5.4(a) and (b) are the morphology revealing the heterogeneous structure of the PKS in its natural form. They show that the sample is made up of micro-pores through which the kernel probably exchanged air and liquid (fluids) with the outer layer in order to sustain its life.

According to Hamdan et al. (2000) palm fruit is drupe oval in shape and contains kernel which is the seed (nut). The kernel is surrounded by the fruit wall made up of hard shell (endocarp), fibrous fruit pulp or oil bearing tissue (mesocarp). The nuts are dried and cracked into palm kernel shell and kernel is separated into palm kernel oil (PKO), palm kernel meal (PKM) and water (Akinoso et al, 2009). The micrograph obtained showed that there is even distribution of the fillers in the polymer matrix for all formulation investigated as shown in Figure 5.4. The micrograph suggested formation of good interface between the filler phase and the matrix phase which is a well desired property in composite fabrication. It also showed a satisfactory adherence as a consequence of the fibrous and irregular nature of the fillers. The observation indicated that fillers were well dispersed in the SEM. The shells are covered with a thin layer of matrix as such a better stress transfer may be expected. The filler-matrix interface composites are tightly connected with the matrix. Then also it is clearly shown from the Figure 5.4(b) that the edge of the shell is rough and the SEM images showed that PKS sample has irregular shaped particles with many pores. Figure 5.4(a) clearly shows the smooth surface of the shell while from the larger scale of this picture Figure 5.4(b), it is clear that the edge of the shell is rough and spiky. The porous morphology as observed may also be attributed to the cracking process of the nut which is organic component, because of this the PKS has higher water absorption capacity, which implies that more pores exist on its surfaces. According to Alengaram et al. (2013), PKS is an organic material with many pores and has higher water absorption within the range of 14-33%. Thus an investigation of PKS microstructure is vital to understand the pore structure and demonstrate the need to use mineral admixture to realize its effect to strengthen the interfacial zone of PKSC.

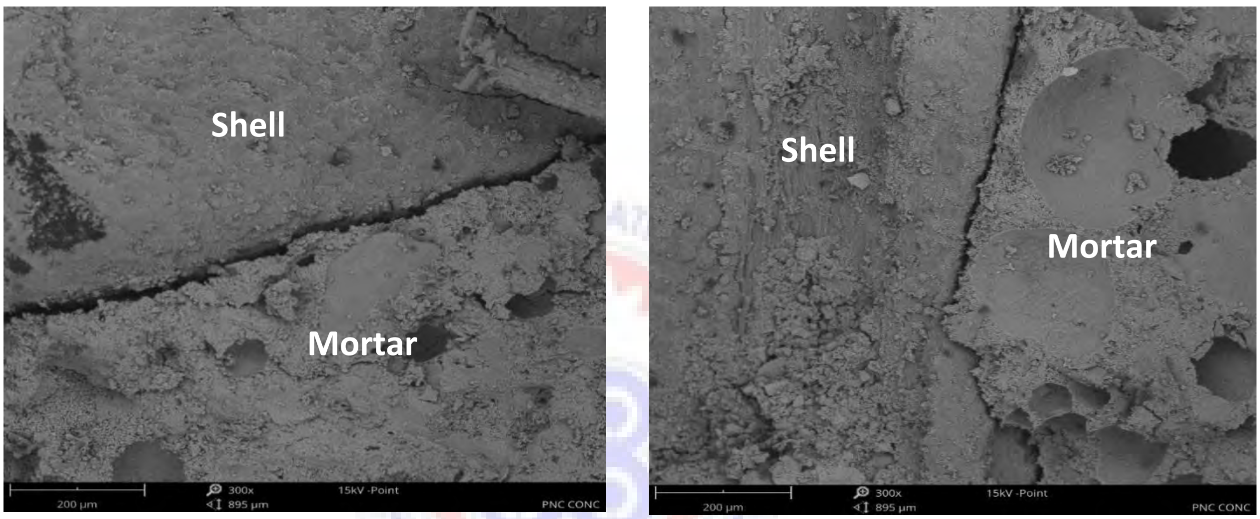


a) **Outer surface** **b) Inner surface**

Figure 5.4: Micrographic images of the raw Palm kennel shell

5.8.1 SEM (Scanning Electron Microscopy) of PKSC

The surface micrograph of the PKSC was examined by using SEM instrument. Figure 5.5 indicates the micrographic images of specimen analysis at the magnification of 300x which shows the surface of PKSC. From the micrographic images, it is clearly shown that there are a lot of voids in the specimen and it is a fact that PKS has absorptive nature, which these factors contributed to lower compressive strength values for this study. Then also PKS has curve and flat shapes, thus it will prevent the approach of the sand as well as disturb the granular arrangement which subsequently lead to reduce the compactness (Figure 5.4). From Table 5.4 in comparison of the shell sizes, the 8mm of PKS size recorded lower compressive strength which might be because of PKS has more curved shapes and thus resulted in more void content. Moreover, the hollow side of PKS might have difficulty to fill with cementitious paste in the concrete which it can be contributed to decrease in compressive strength. In addition, the porosity of PKS plays an important role in reducing the compressive strength of PKSC mixtures. Scanning Electron Microscopy of PKS revealed a highly porous structure of the shell (Figure5.4). Moreover, the reduction in compressive strength can be also because the PKS has a strong water absorption capacity. The compressive strength values obtained were lower than the minimum characteristic strength of LWC as specified by British code of practice BS 8110(1997). The lower compressive strength of PKSC may be due to the smooth surface texture of the shell for both convex and concave faces. Shafigh et al. (2011) recommended that the strength of LWAC depends on the strength of the LWA used and hardened cement paste, as well as the bonding of the aggregate and cement paste in the interfacial zone. Figure4.5 indicated there is a gap between the shell and mortar in the interfacial zone which has effect on the strength of the specimen. According to Neville (1996) to achieve a higher compressive strength may be attributed to fineness of silica fume and reaction between the silicon dioxide and calcium hydroxide. The infilling of the voids in the shells by very fine silica fume particles may have increased the bond between the PKS and cement matrix.



a. 7-day PKSC **b. 28-day PKSC**

Figure 5.5: Micrographic images of the specimen

5.9. Energy Dispersive Spectroscopy (EDS) Analysis Result

The chemical composition of PKS samples especially wood based material is quite different from other lightweight aggregate materials such as expanded shale, pumice, vermiculite, perlite. Cellulose fibers are responsible for the strength of the wood nature of PKS. Table 5.12 presents the chemical composition percentage of the PKSC showing the presence of the large concentration of oxygen and very little magnesium value. The EDS results in Table 5.12 and its spectrum Figure 5.6 (X-Ray Powder Diffraction) show the presence of other elements such as carbon, calcium, nitrogen, aluminum, silicon and iron, in the PKSC. Although these elements are in trace quantity when compared with carbon and oxygen they play significant role in presenting the sample good for material filler in construction industry. It is the presence of silicon that gives the sample its crystalline property.

Table 5.12: Chemical elements in the specimen

Element				Oxide	
Symbol	Name	Atomic concentration (%)	Weight concentration (%)	Symbol	Stoichiometric weight (%)
O	Oxygen	54.67	51.26		
C	Carbon	24.69	17.38	C	35.65
Ca	Calcium	5.68	13.33	Ca	27.35
Si	Silicon	4.6	7.57	Si	15.53
N	Nitrogen	8.59	7.05	N	14.46
Al	Aluminium	1.09	1.73	Al	3.55
Fe	Iron	0.38	1.26	Fe	2.58
Mg	Magnesium	0.3	0.42	Mg	0.87

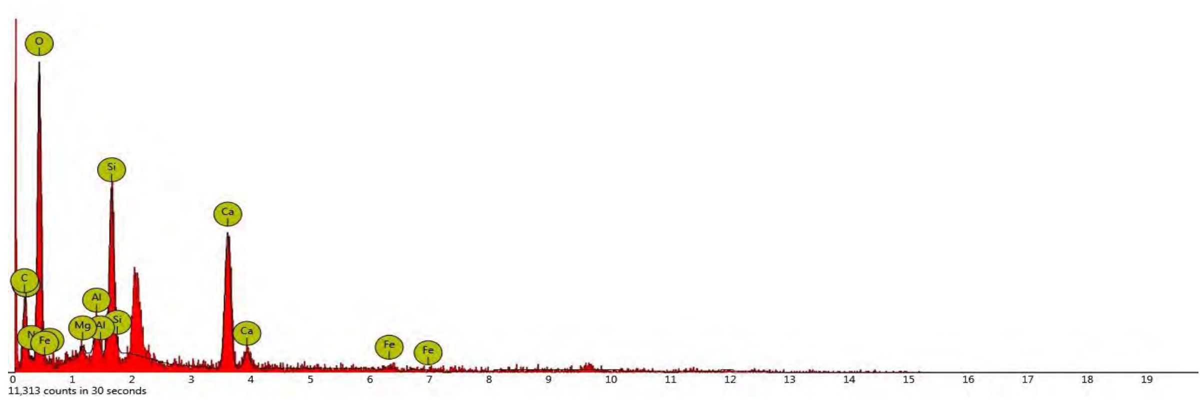


Figure 5.6 XRD of the Palm kernel shell concrete sample

5.10. Discussion of results

The density of the PKSC was found to meet the prescription of America Society for Testing of Materials ASTM and British Standards Institution BS. The results of the characterization of the PKS used in this research for the production of specimen concrete cubes have shown that it met the requirements for use as aggregate in lightweight concrete. The minimum and maximum concrete densities of 1447.27 kg/m^3 and 1714.27 kg/m^3 for 6mm and 10mm PKS replacement respectively. The minimum and maximum densities were observed at 21 days of curing time. Conversely, the range for density of structural lightweight concrete is 1440-1850kg/m^3(ACI 213R-87,2003). From the results of Table 4.3 and Figure 4.1, the density of 1509.73kg/m^3, 1497kg/m^3, 1624.13kg/m^3, 1685kg/m^3 and 1610.47kg/m^3 respectively recorded for full replacement at curing age of 28 days which falls within the range for structural LWC and suggests that PKS can be used as structural lightweight concrete (ASTM C330,2004). ASTM C330-04(2004) defines the density of structural lightweight concrete as concrete having dry density not exceeding 1840kg/m^3. The values obtained for this study were the exact numerical value of 28 days- dry bulk density of PKSC which did not exceed 1840kg/m^3.

On the other hand, Alengaram et al, (2010) examined the effect of aggregate size and proportion on strength properties of PKSC. Their research presented information on the physical and mechanical properties of different sizes of PKS used here as LWA and their influence on mechanical properties of PKSC. Silica fume and fly ash were used as cementitious materials and all mixes had 1% superplasticizer on cement weight. They reported that PKS consists of about 65-70% of medium size particles in the range of 5 to 10mm. The other two sizes namely small (0-5mm) and large (10-15mm) size were found to influence the mechanical properties of PKSC. The 28- days compressive strength were found in the range of 21-26MPa. The concrete mix that was made with medium size PKS only produced lower compressive strength of about 11% compared to the mix that contained all sizes of PKS. In addition, Babafemi & Olusola (2012) investigated the influence of curing media on the compressive strength of PKSC with varying coarse aggregate size (5-10mm,5-14mm and 5-20mm) and replacement level of granite with PKS (0-100% in steps of 25%). The results showed that the compressive strength was significantly influenced by the curing media. Compressive strength of PKSC decreased from curing media CM-1 to CM-3(CM-1: Complete Immersion; CM-2: Partial Immersion; CM-3: No Immersion). In their study, the compressive strength of PKS concrete increased with increase in aggregate sizes at all curing media. Optimum strength at 28 days was obtained for 5-20mm aggregate size at 25% PKS content. However, at 50% PKS content which is lightweight, compressive strength was 18.43 N/mm^2 for 5-20mm aggregate specimen which is above the minimum value of 17 N/mm^2 for LWC. Then also the specimens cured by complete immersion in water for the test period gave the highest compressive strength at all aggregate sizes and PKS content.

Furthermore, Acheampong et al. (2013) worked on the comparative study of the physical properties of PKSC and normal weight concrete (NWC) in Ghana. Their work present results of a comparatively study of the physical and compressive strength of PKSC and NWC using Portland-Limestone Cement (Class 32.5R) and Ordinary Portland Cement herein called Ghana Extra Cement (Class 42.5N). PKS were used as LWA in PKSC and granite was used as aggregate for the normal concrete. The density of PKSC was about 22% lower than that of NWC for both cement types. Compressive strengths of both PKSC and NWC with Portland-Limestone Cement and Ghacem Extra Cement evaluated at 7,14 and 28 days showed that Ghacem Extra Cement produced concrete of higher compressive strengths than Portland-limestone Cement for PKSC and NWC. The 28 day strengths of PKSC produced from Portland-Limestone Cement and Ghacem Extra Cement were 24.47 N/mm^2 and 27.47N/mm^2 respectively, while that of NWC produced from Portland-Limestone Cement and Ghacem Extra Cement were 33.29 and 37.62 N/mm^2. On the contrary, Kilic et al. (2009) examined the effect of Scoria and the pumice aggregate on the strengths and unit weights of LWAC. Different aggregate sizes were used in their study and found that with a density range of 1368 to 1997 kg/m^3, cylinder compressive strengths of 15.8 MPa to 44.1 MPa could be achieved.

In contrast to the previous studies, Alengaram et al. (2010) used silica fume and fly ash to enhance the compressive strength of PKSC. Then also in their work PKS size particles used were ranged of 0-5, 5-10 and 10-15mm which was classified as small, medium and large respectively. In line with this study, the PKS size particles used was ranged with specific size namely; 6mm, 8mm, 10mm, 12mm and mix up. In this study superplasticizer was not added to the PKSC mixture to enhance the mechanical properties, which also it can be contributed factor which led to the lower compressive strength values. Moreover, Babafemi and Olusola (2012) considered the influence of curing media on the compressive strength of PKSC with varying aggregate size (5-10, 5-14 and 5-20mm). Their study recommended that the curing media or method in complete immersion of water was best for PKSC but this study used non immersion curing method thus sprinkled water on the jute sack which may be factor led to lower compressive strength values. However, in their study at 50% PKS content compressive strength obtained was 18.47 N/mm^2 for 5-20mm aggregate specimen which is above the minimum value of 17 Nmm^2 for LWC, this indicates that 75% and 100% PKS content produced lower compressive strength values below the prescription in BS 8110(1997). Furthermore, Acheampong et al. (2013) compared the properties of PKSC and NWC using Portland-Limestone Cement (32.5R) and Ordinary Portland Cement (42.5N). The Ghacem Extra Cement (42.5N) produced higher compressive strength for both PKSC and NWC. They used specific aggregate size 14mm but it produced higher compressive strength values above prescription in BS 8110(1997). These reasons can be contributing factors; firstly, a lot of PKS used do not have flat and curved shape. Secondly, may be old crushed PKS whose surface texture of the shell for the convex and concave faces are not smooth. Lastly, the complete immersion curing method used help to improve the compressive strength values for that research work. In the above stated conditions have significant effect on the mechanical properties of PKSC. It can be observed from the previous studies on LWA from Kilic et al. (2009) that the values they obtained for average compressive strength were higher than prescription of BS 8110-1(1997) which may be due to fly ash and silica fume added to the mixture. Then also they obtained high values for density which is above the prescription in the ASTM C330-04(2004). However, studies done by Zaetang et al. (2013) achieved 28 day compressive strengths of lightweight concrete which ranged from 2.47to 5MPa. They used pumice and diatomite a natural LWAs in that study. Then also Williams et al. (2014) used PKS as a full replacement coarse aggregate in LWC production but they achieved lower compressive strength values for 28-days of curing.

In conclusion, this study lower compressive strength values obtained were 4.100N/mm^2, 3.833N/mm^2, 5.167N/mm^2, 6.500N/mm^2 and 5.767N/mm^2 for their various specific sizes 6mm,8mm,10mm,12mm and Mixed up respectively. Furthermore, in this study, admixture was not added to mixture and PKS has high absorptive nature which has effect on the concrete to obtain low compressive strength values. Non immersion method of curing used in this study was a key factor which led to lower strength values. Then also studies showed that curing method has influence on the compressive strength. Table 4.4 shown the values for compressive strength less than the recommended minimum value for compressive strength of LWC which should be equal to 15N/mm^2 or more specified by BS 8110-1(1997). On the other hand, Neville (1996) said higher compressive strength may be attributed to fineness of silica fume and reaction between silicon dioxide and calcium hydroxide. The infilling of the voids in the shells by very fine silica fume particles may have increased the bond between PKS and cement paste. Then also the silicon dioxide from silica fume particles react with the liberated calcium hydroxide from cement hydration to produce calcium silicate and aluminate hydrates. This pozzolanic reaction increases the strength and reduces the permeability by densifying the matrix of the concrete (Neville.1996; Robert et al, 2003).

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This chapter contains the summary of the study with respect to the objectives and findings; recommendations of the study; future research agenda; and conclusion of the study. It further outlines the contributions this research has made to knowledge as well as its effect on the construction industry.

6.2 Summary of findings

The findings established from the analysis of the data have been related to the objectives of the study in this section.

6.2.1 Dry average density

From the results in this study, the dry density values obtained were 1509.73kg/m^3,1497kg/m^3,1624.13kg/m^3, 1685kg/m^3 and 1610.47kg/m^3 for the various specific sizes 6mm,8mm,10mm,12mm and Mixed up respectively. These values were recorded for full replacement at curing age of 28 days which falls within the range for structural LWC and suggests that PKS can be used as structural lightweight concrete (ASTM C330,2004).

6.2.2 Compressive strength

The compressive strength of the samples increases as the curing age increases. For example, the aggregate sizes of 6mm,8mm,10mm,12mm and Mixed PKS content, at 7 day recorded an average compressive strength of 3.533 N/mm^2, 3.133 N/mm^2,3.400 N/mm^2,5.567 N/mm^2 and 4.700 N/mm^2 respectively. The average compressive strength for 28-day were 4.100N/mm^2, 3.833N/mm^2, 5.167N/mm^2, 6.500N/mm and 5.767N/mm^2 for aggregate sizes of 6mm, 8mm, 10mm, 12mm and Mixed PKS content respectively.

6.2.3 Flexural strength

Table 4.5 shows the strength values of 0.83 N/mm^2, 0.936 N/mm^2, 1.761 N/mm^2, 2.185 N/mm^2 and 1.467 N/mm^2 for 28-day curing with for specific size 6mm, 8mm, 10mm, 12mm and Mix up respectively. The variation in flexural between the various coarse aggregate sizes were mainly due to the lower strength and stiffness of the PKS. The presence of high volume of pores in PKS because of its high water absorption may weaken the particle strength and stiffness.

6.2.4 SEM (Scanning Electron Microscopy of PKSC)

From the micrographic images, it is clearly shown that there are a lot of voids in the specimen and it is a fact that PKS has absorptive nature and these factors contributed to lower compressive strength values obtained in this study. Then also PKS has curve and flat shape, thus it will prevent the approach of the sand as well as disturb the granular arrangement which subsequently lead to reduce the compactness.

6.2.5 EDS Analysis Result (Energy Dispersive Spectroscopy)

The chemical composition percentage of the PKSC showing the presence of the large concentration of oxygen and very little magnesium value. The EDS results and its spectrum

(X-Ray Powder Diffraction) show the presence of other elements such as carbon, calcium, nitrogen, aluminum, silicon and iron, in the PKSC.

6.2.6 Findings from the Study

The concrete specimen cubes under compression testing machine, they experienced the gradual crack without any explosive sound. This could be attributed to the relative lower density of PKSC as it plays role in the reduction of dead load.

The physical properties of PKS such as specific gravity, shell thickness, bulk density and water absorption indicated that it has the properties of lightweight aggregate.

The size of PKS was found to significantly influence the granular arrangement of the concrete matrix. Consequently, it also affected both compressive and flexural strength. However, the smaller size of PKS was able to fit into pores and thus decreased the void content. In comparison, the larger PKS disrupted the granular arrangement which subsequently resulted in decreased mechanical strength.

6.3 Conclusion

This research work vividly shows that PKS can be used for concrete production as lightweight aggregate and therefore can be used to produce lightweight concrete.

In other to reduce the cost of constructing buildings, PKSC can partially replace normal coarse aggregate to get a desired strength in building construction projects.

The compressive and flexural strength of concrete generally increase with increase in the curing age but they obtained lower strength values.

The dry average density of PKSC is in the range of 1447.27 to 1714.27 kg/m^3 which less than maximum of 1840 kg/m^3 specified by ASTM C330 (2004).

The water absorption capacity was much higher especially 6mm aggregate size but all the various aggregate sizes of PKS values fall within the specification sated by Concrete Society of UK,1987.

The specific gravity values obtained for the various aggregate sizes were below the limits (2.3 to 2.9) specified by ACI Education Bulletin EI (2007) which indicated that the PKS is a suitable lightweight aggregate.

The results of this study indicated that the various aggregates sizes have significant effect on the average dry density, compressive and flexural strength.

6.4 Recommendations

- From the results of the study, aggregate size 12mm recorded maximum values for most of the test results and therefore it is recommended to be partially mixed with granite to produce a desirable concrete for a sustainable construction.
- Plasticizers should be used in construction works involving PKS concrete to enhance the strength to meet the standards for structural LWC.
- Stakeholders should take advantage of the positive effect of the sustainable materials such as PKS in construction to prevent the environmental pollution especially reducing mining activities for natural aggregate, indiscriminate burning and dumping of PKS.

6.5 Further research

- More research works should be done on PKSC mix design and water/cement ratios to further evaluate their influences on concrete strength.
- Lime can be used as a binder for PKSC to study the mechanical properties.
- More research is needed to reduce water absorptive nature of PKSC by using admixtures.

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APPENDICES

APPENDIX A

SUMMARY OF EXPERIMENTAL MATERIALS.

Measurement of Materials for Preparation of Specimens

Parameters:

Mix ratio = 1:2:3

Where: 1 represents One part of Cement in weight

2 represents Two parts of Sand in weight

3 represents Three parts of PKS in weight

Volume of 1 cube specimen = $0.001m^3$ ……………………… Equation 1

For 12 specimens = 12 × 0.001

= $0.012m^3$

Volume of 1 beam specimen = $0.005m^3$ ……………………… Equation 2

For 12 specimens = 12 × 0.005

= $0.06m^3$

Total = (Equation 1 + Equation 2) …………………………… Equation 3

Total = 0.012 + 0.06

Total = $0.072m^3$

Add Waste of Material = 5% ………………………………… Equation 4

= 0.05 × 0.072

= $0.0036m^3$

Total Volume for 24 specimens = (Equation 3 + Equation 4) ……………. Equation 5

Total Volume = 0.072 + 0.0036

= $0.076m^3$

Density = $\frac{Mass\ (M)}{Volume\ (v)}$

For average density of PKS = $1800kgm^3$

Mass = Density × Volume

M = $1800kgm^3 \times 0.076m^3$

M = 136.8 or 137 kg

Calculating for Materials in the Mix

Mix Ratio (1:2:3) = 6

Cement = 1/6 × 137 kg

= 22.83 or 23 kg

Sand = 2/6 × 137 kg

= 45.66 or 46 kg

PKS = 3/6 × 137 kg

= 68.5 kg or 69 kg

Calculating for Amount of Water in the Mix

Water/Cement Ratio = 0.06

Water = W/C ratio × Cement weight

Water = 0.06 × 23

Water = 13.8 or 14kg

Summary of Materials for 5 batches

PKSC	Cement	Sand	PKS	Water
24 specimens	23 kg	46 kg	69 kg	14 kg
120 specimens	115 kg	230 kg	345 kg	70 kg

APPENDIX B

Table 4.1 Sieve Analysis (Grading) of Sand

Sieves (mm)	Mass Retained (g)	Retained (%)	Passing (%)
5	-	0	100
2.36	13	1.2	98.8
1.18	236	21.9	76.9
600um	252	23.4	53.5
300um	234	21.7	31.8
150um	144	13.3	18.5
Pan	200	18.5	0
Total	**1079**	**100**	

Calculation of Percentage Retained on Sieve

The following formula was used to calculate the percentage of Soil retained on the sieve using the results obtained in table above.

Percentage Retained = $\frac{Mass\ of\ Soil\ Retained\ on\ Sieve}{Total\ Mass\ of\ Sample} x100$

Total Mass of Sample = 1079 g

Mass of Soil retained on the 2.6 mm Sieve = 13 g

Therefore, Percentage Retained $= \frac{13}{1076} x100$

= 1.2 %

Mass of Soil retained on the 1.18mm Sieve = 236 g

Therefore, Percentage Retained = $\frac{236}{1076} x100$

= 21.9 %

Mass of Soil retained on the 600um Sieve = 252 g

Therefore, Percentage Retained = $\frac{252}{1076} x100$

= 23.4 %

Mass of Soil retained on the 300um Sieve = 234 g

Therefore, Percentage Retained = $\frac{234}{1076} x100$

= 21.7 %

Mass of Soil retained on the 150um Sieve = 144 g

Therefore, Percentage Retained = $\frac{144}{1076} x100$

= 13.3 %

Mass of Soil retained less than 150um Sieve = 200 g

Therefore, Percentage Retained = $\frac{200}{1076} x100$

= 18.5 %

Calculation of Percentage of Soil Passing each Sieve

The values obtained in the table above captioned percentage of Soil retained were used to calculate the percentage passing each sieve. The calculation started at the top by deducting the cumulative value from 100. The value 100 in this case is once again the percentage value.

1) Percentage of Soil passing the 5mm Sieve = 100 - 0 = 100
2) Percentage of Soil passing the 2.36 mm Sieve = 100 - 1.2 = 98.8 %
3) Percentage of Soil passing the 1.18 mm Sieve = 98.8 – 21.9 = 76.9 %
4) Percentage of Soil passing the 600um Sieve = 76.9 – 23.4 = 53.5 %
5) Percentage of Soil passing the 300um Sieve = 53.5 – 21.7 = 31.8 %
6) Percentage of Soil passing the 15oum Sieve = 31.8 – 13.3 = 18.5%
7) Percentage of Soil less than 150um Sieve = 18.5 -18.5 = 0.

APPENDIX C

RESULTS FOR BULK DENSITY DETERMINATION

PKS Size (mm)	**W_1(g)**	**W_2(g)**	**W_3 (kg)**	**Volume (m^3)**	**Bulk density (kg/m^3)**
6	2993	4675	1.682	0.002651	634
8	2995	4617	1.662	0.002651	611
12	2995	4561	1.566	0.002651	591
10	2993	4530	1.537	0.002651	580
Mix	2995	4672	1.677	0.002651	633
Sand	2995	6998	4003	0.002651	1509

Bulk density = $\frac{weight\ of\ sample\ (w3)}{volume\ of\ mould\ (v)}$

Where W_1= Weight of empty mould (g)

W_2 = Weight of mould + Sample (g)

W_3 = Weight of Sample ($W_3 = W_2 - W_1$)

Calculating for the Volume of Cylinder (mould)

Volume of mould $(v) = \pi r^2 h$

Where radius (r) = 7.5cm, height (h) = 15cm, π = 3.143

Volume of mould $(v) = 3.143(7.5^2)(15)$

Volume of mould (v) = 2651cm

Volume of mould (v) = 0.002651m^3

APPENDIX D

RESULT FOR ABSORPTION DETERMINATION FOR 24H

PKS Sizes (mm)	W_1(g)	W_2(g)	$W_3 = (W_2 - W_1)$	Absorption = $\frac{w2-w1}{w1} x100$
6	383	462	79	21%
8	364	418	54	15%
10	409	457	48	12%
12	345	394	49	14%
Mix	423	472	49	11.6%
Sand	1065	1071	6	0.56%

Water absorption = $\frac{W2-W1}{W1} x100$

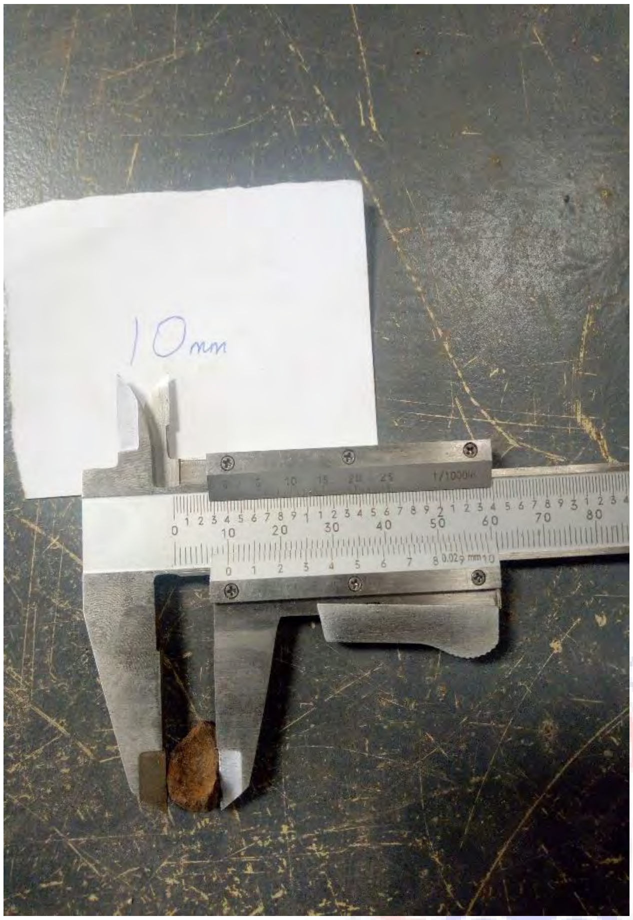
$Where\ W1 = weight\ of\ sun\ dried\ smaple$

$W2 = weight\ of\ sample\ after\ 1h\ divided\ by\ 24h\ immersion\ in\ water.$

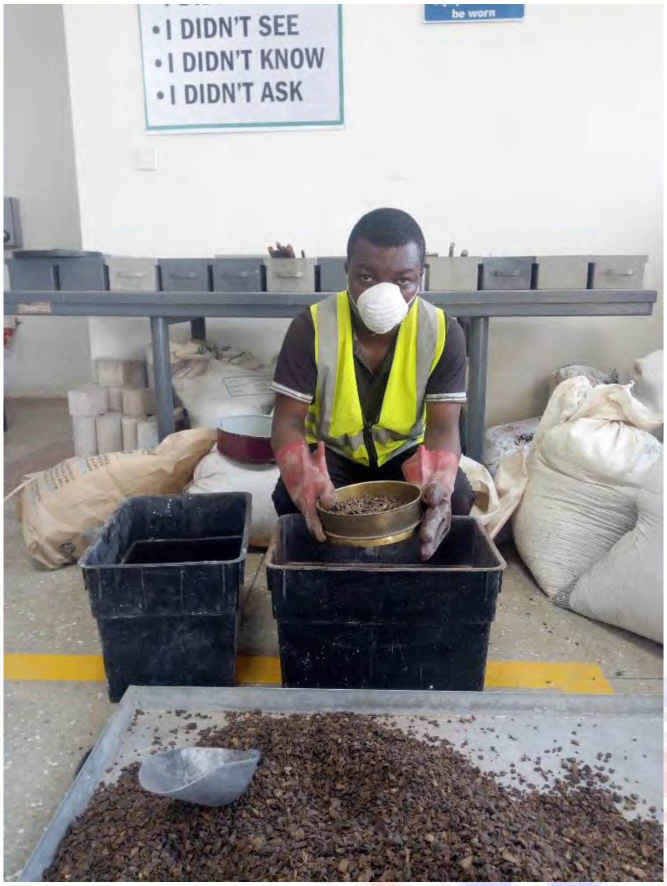
$W3 = weight\ of\ water\ absorbed\ (w2 - w1)$

APPENDIX E

Weighting of Samples for Bulk Density



Measuring the thickness of PKS



Sieving of PKS

Drying of PKS after 24 h soaking.

Pouring of Sand onto the Pan Mixer

Casted Concrete Cubes and Beams