UNIVERSITY OF EDUCATION, WINNEBA

COLLEGE OF TECHNOLOGY EDUCATION

USING GRANULAR PALM KERNEL SHELLS TO PARTIALLY REPLACE SAND IN SANDCRETE BRICKS

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JULY, 2017

DECLARATION

STUDENT'S DECLARATION

I, Frank Michael Anyane, declare that this project report, 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 elsewhere.

SIGNATURE:……………………………………………

DATE:…………………………………………

SUPERVISOR'S DECLARATION

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

NAME OF SUPERVISOR: PETER PAA-KOFI YALLEY (PhD)

SIGNATURE:…………………………………………………..

DATE:……………………………………………

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To God be the glory.

DEDICATION

I dedicate this project to my children, Kwadwo Adu Boateng Anyane, David Ohene Anyane and Adwoa Nsoroma Anyane.

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ABSTRACT

A study into the use of granular palm kernel shells (PKS) of varying sizes to partially replace sand in sandcrete bricks was conducted. Portland cement, Palm Kernel Shell-PKS, and portable water were used. PKS sizes used include 1.18mm, 2.36mm and 4.75mm. The materials were batched using 1:3 mix ratio where the sand content was replaced with PKS at 10%, 20% and 30%. A total population of 150 specimens was used for the study with 3 samples in each group to test compressive strength (wet and dry), split tensile strength, water absorption and abrasion resistance. All specimens were tested after 28 days curing. Significant difference was tested using ANOVA. The study shows that the addition of PKS to replace sand content generally and significantly reduced the compressive strength of brick specimen with the exception of 4.75mm size of PKS with 10% and 20% replacement compared to the control. Moreover, the compressive strength of brick increased as the PKS size increased but decreased as the percentage of replacement increased. The same trend was found for split tensile strength. The study recommended that the Government of Ghana should empower Civil engineers and contractors to use palm kernel shell (PKS) aggregate as a replacement in conventional sandcrete bricks in the locality where it is in abundance to enhance environmental cleanliness.

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

The history of building construction is intimately related to the availability of suitable building materials and the ability of craftsmen and engineers to exploit their properties of strength and durability (Becche, Corradi, Foece & Pedemonte, 2004). Thus, traditionally earth and clay bricks, with stone and timber were widely used for construction, but the industrial revolution introduced wide application of wrought iron and steel which necessitated a stronger and more durable option. Consequently, concrete and sandcrete begun to play an important role in construction during the late 19th century, and by the mid-20th century, their application in both domestic and industrial construction had gone worldwide (Addis, 2007).

According to Mehta and Montero (2006), sandcrete is popular because it has good resistance to water, structural sandcrete elements can be formed into a variety of shapes and sizes and it is usually the most readily available material for the job. Owing to the evolution of construction needs, some studies have made considerable effort in experimenting with lightweight concrete, which are generally cheaper alternative to sandcrete (Oyekan & Kamito, 2011). Moreover, lightweight concrete offers better fire resistance, heat insulation, sound absorption, frost resistance, superior anti-condensation properties and increased damping (Chandra & Berntsson, 2002; Shafigh, Jumaat & Mahmud, 2010).

According to Polat, Demirbo, Karakoc and Turkmen (2010), the most popular way of achieving light weight concrete production is by using lightweight aggregate

(LWA), which may be subdivided into natural and manufactured aggregates. The main natural LWAs are diatomite, pumice, scoria, volcanic cinders and tuff (Neville & Brooks, 2008; Shafigh et al., 2010). On the other hand, manufactured aggregates occur as industrial by products, such as sintered pulverized-fuel ash (fly ash), sintered slate and colliery waste, foamed or expanded blast-furnace slag (Neville, 2008).

In this respects, several construction industries have identified many artificial and natural lightweight aggregates that have replaced granite and sand aggregates thereby reducing the size of structural members (Basri, Mannan & Zain, 2009). One area of interest in terms of natural lightweight aggregates is the use of palm kernel shells (PKS) and coconut shells as additives or substitutes to conventional common coarse aggregates in concrete and sandcrete production (Ndoke, 2006; Owolabi & Adebayo, 2012).

While environmental and waste management concerns abound, some advocates emphasise recycling agro-waste as aggregates for building blocks (Agopyan, 2011; Rabi, Santos, Tonoli & Savasto, 2009). This is because, the utilisation of this agricultural solid waste as a lightweight aggregate in the construction industry reduces the cost of construction materials and also resolves the problem concerning the disposal of agro-waste (Shafigh et al., 2010).

In this field, Ata, Olanipekun and Olulola (2006) experimented with coconut shell as coarse aggregates and concluded that the conventional aggregates of concrete could not be adequately substituted with coconut shells. Similarly, Owolabi and Adebayo (2012) used palm kernel shells as aggregate in concrete and laterite blocks and concluded that palm kernel shells are not good substitutes for crushed stone aggregates in concrete. In another study, Owolabi and Dada (2012) partially replaced Portland cement with cocoa and palm kernel shell ashes to stabilize blocks for road construction and asserted that the additives could serve as partial replacement of cement.

On the other hand, Basri et al. (2009) maintain that in most cases, the comprehensive strength of sandcrete blocks with PKS as aggregate is within the normal range for structural lightweight concrete. Furthermore, it was found that PKS structural lightweight concrete is a good thermal performance material for low cost housing (Harimi et al., 2007). Alengaram, Jumaat and Mahmud (2008) and Olutoge (2010) also found that palm kernel reinforcements improved ductility (modulus of elasticity), moment capacity of concrete beams and also exhibited higher deflection under constant load until failure. Similarly, Kaur and Kaur (2012) found that the long-term bonding properties of blocks increased when natural shells, PKS are used as aggregates of sandcrete.

Following these studies, the empirical evidence about the absolute advantage or disadvantage of substituting or replacing conventional granite aggregates with natural shells seems inconclusive. Nevertheless, some studies strongly advocate in favour of PKS as coarse or fine aggregates, because the shell is hard and does not easily suffer deterioration and has a good resistance to wear (Basri et al., 2009). Furthermore, the aggregate impact value and aggregate crushing value of PKS aggregates were much lower compared to conventional crushed stone aggregates, indicating that the aggregate has a good absorbance to shock (Teo et al., 2007). Ramezanianpour, Mahdikhani and Ahmadibeni (2009) add that lightweight PKS concrete has cost advantage due to the ready availability of PKS as cheap substitutes, especially in the tropical and sub-tropical regions where most developing countries are located.

Oyekan and Kamiyo (2008) note that sandcrete blocks containing a mixture of sand, cement and water are widely used, especially in Africa. In countries such as Nigeria (Aguwa, 2009) and Ghana (Osei & Jackson, 2012), sandcrete block is the major cost component of the most common buildings. However, the high and increasing cost of constituent materials of sandcrete blocks has contributed to the non-realisation of adequate housing for both urban and rural dwellers (Oyekan & Kamiyo, 2011).

Some studies also note that the rising cost of sand has also led to the production of sub-standard blocks that tend to have high rate of block-failure and poor mechanical properties in relation to their modulus of elasticity, shrinkage limit, maximum dry density, comprehensive strength, optimum moisture content, abrasion resistance and efflorescence or surface powdering (Kaur & Kaur, 2012; Teo et al, 2007). For example, in Ghana, Agyei (2008) found that some sandcrete blocks exhibit comprehensive strength as low as 1.8N/mm^2 as against the recommended strength of 2.8N/mm^2. Hence, availability of alternatives to these materials for construction is very desirable in both short and long terms, with particular reference to cheaper materials that can complement cement (Osei & Jackson, 2012).

Traditionally, in Ghana, palm kernel shells were used as cheap coarse aggregates and binding agents in laterite walling units, as in wattle and daub or adobe blocks (Arhin & Nude, 2009). However, reports from the Ghana Harbours and Ports Authority shows that, since 2004, Ghana has been exporting about 200,000 tonnes of palm kernel shells annually. However, twice as much as exported palm kernel shells still go to waste and create disposal problems. In construction, palm kernel shells have been incorporated as raw materials, in producing puzzolanic ash, since the establishment of Pozzolana Ghana Limited in 2007 (Pozzolana Ghana Limited, 2012).

Nevertheless, studies have shown that a more direct application of palm kernel shells as coarse or fine aggregates in block production is still viable (Ata et al., 2006; Basri et al., 2009). This study thus focuses on testing assumptions and hypothesised engineering properties of partially replaced PKS fortified sandcrete bricks. This is pursued in order to find cheaper and comparatively durable alternatives to conventional sandcrete aggregates.

Sandcrete has gained popularity especially in the African sub-region due to its good water resistance and the fact that structural sandcrete elements can be formed into a variety of shapes and sizes (Awuga, 2009; Oyekan & Kamito, 2008). Moreover, the aggregates of sandcrete are usually the most readily available material for the job (Mehta & Montero, 2006). However, lightweight concrete offers better fire resistance, heat insulation, sound absorption, and superior anti-condensation properties, which are important for housing units in hot tropical regions (Chandra & Berntsson, 2002; Oyekan & Kamito, 2011).

According to Polat et al. (2010), the most popular way of achieving light weight concrete production is by using lightweight aggregate, which are available in the tropics, as cheap agro-waste. However, the experiments still remain inconclusive on the suitability of substituting conventional aggregates with LWAs. This is because, while some studies maintain that LWA additives lowers the mechanical properties of concrete (Ata et al., 2006; Owolabi & Adebayo, 2012), others found that LWA additives enhance the engineering properties of sandcrete, such as thermal performance, ductility and abrasion resistance (Harimi et al., 2007; Alengaram et al., 2008).

1.2 Statement of the Problem

According to Polat et al. (2010), the most popular way of achieving light weight concrete production is by using lightweight aggregates, which are available in the tropics, as cheap agro-waste. However, the experiments still remain inconclusive on the suitability of substituting conventional aggregates with LWAs. This is because, while some studies maintain that LWA additives lowers the mechanical properties of concrete (Ata et al., 2006; Owolabi & Adebayo, 2012), others found that LWA additives enhance the engineering properties of sandcrete, such as thermal performance, ductility and abrasion resistance (Harimi et al., 2007; Alengaram et al., 2008).

A consensus exists that the rising cost of sand has led to the production of sub-standard blocks that tend to have high rate of block-failure and poor mechanical properties. Besides, the cost of sand has had a major influence on the cost of sandcrete blocks which often results in the use of affordable but low quality sand that ends up with substandard blocks for housing construction. The situation has led to the inability to achieve adequate housing in the nation. Thus cheaper, but comparatively durable alternatives such as lightweight blocks are desirable. This necessitates a study into the physical and engineering properties of PKS fortified bricks to ascertain the possibility of partially or completely replacing sand aggregates in the production of lightweight bricks.

1.3 Objectives of the Study

The general objective of the study is to assess the mechanical and durability properties of granular PKS lightweight sandcrete bricks. Specifically, the study aims to:

1. Examine the size effect and percentage of palm kernel shell on the compressive strength of brick specimens.
2. Determine the size effect and percentage of palm kernel shell on the split tensile strength of sandcrete brick specimens.
3. Assess the size effect and percentage of palm kernel on the water absorption of sandcrete brick specimens.
4. Examine the size effect and percentage of palm kernel shell on the abrasion resistance of sandcrete brick specimens.

1.4 Research questions

The following research questions were investigated by the study:

1. What is the size effect and percentage of palm kernel shell on the compressive strength of brick specimens?
2. What is the size effect and percentage of palm kernel shell on the split tensile strength of sandcrete brick specimens?
3. What is the size effect and percentage of palm kernel on the water absorption of sandcrete brick specimens?
4. What is the size effect and percentage of palm kernel shell on the abrasion resistance of sandcrete brick specimens?

1.5 Scope of the Study

The study covers literature on sandcrete and associated potentials with granular PKS replacing sand in varying volumes in sandcrete bricks. The conceptual issues will be confined to engineering properties of granular PKS sandcrete bricks. This will include the comprehensive dry/wet strength, density, absorption, and abrasion resistance. These properties will be tested for both modified and conventional sandcrete bricks.

1.6 Significance of the Study

The study is intended to provide a further insight into the physical and mechanical properties of PKS sandcrete bricks. This can be important for further studies into sandcrete modification and the potential of substituting conventional sandcrete with cheaper lightweight bricks. The study can also assist in finding alternative uses for agro-waste materials, such as palm kernel shells and also provide an approach to managing agro-waste. The feasibility of generating income from agro-waste, such as PKS is also implied in the study.

1.7 Organization of the Study

The study is divided into six chapters. The introductory chapter which is chapter one explains the background of the study, statement of the problem, the objectives of the study, research questions, scope and significance of the study and the organization of the study. Chapter two contains a review of the relevant literature on the mechanical properties of sandcrete and empirical experiments that have been conducted to test the attributes of PKS sandcrete bricks. Chapter three presents the methodology by discussing the research design, the materials and methods, as well as data collection techniques and data analysis. Chapter four presents the results and findings of the study. Chapter five discusses and interprets significant findings identified in the study while Chapter six which is the concluding chapter, presents the summary, conclusions and recommendations of the study.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 Introduction

This chapter discusses the relevant literature on the engineering properties of bricks and empirical experiments that have been conducted to test these attributes. The concepts to be discussed as sub-headings include the processes and methods of measuring and assessing the engineering properties of PKS fortified sandcrete bricks. Empirical studies on the strength attributes of bricks are discussed to form a basis for comparism with the empirical analysis of this study.

2.2 The Need for Seeking Alternative for Sand

The Ghanaian Construction Industry is likely to face a shortage of sand in near future due to over exploitation of sand from rivers, pits and sea shore. A study by Aromolaran (2012) indicates that there is increase in demand for sand for construction and other purposes as communities grow to construction at present requires less wood and more concrete, which sprout a demand for low-cost sand or other alternatives. The possible ecological impact of these indiscriminate sand mining and threats to the livelihoods of local communities includes the depletion of groundwater; lesser availability of water for industrial, agricultural and drinking purposes; destruction of agricultural land; loss of employment to farm workers, and damage to farm roads and bridges. More so, there are considerable pressures to reduce the consumption of primary aggregate for the environment reasons. Extracting large quantities of material from quarries or pits can cause loss of valuable or scenic land, dust and noise emissions and extra-traffic on unsuitable rural roads. Near-shore dredging can as well disturb wave and current flow, causing unwanted seabed movement (Domone and Illston, 2010). It is reported that over 90% of physical infrastructure in Ghana, Nigeria and other African countries are being constructed using sandcrete blocks (Oyebade and Anosike, 2012). Sarndcrete blocks according to Joshua and Lawal (2011), are constructional masonry units that have been generally accepted to the extent that when an average individual thinks of building, the default mindset is the use of sandcrete blocks.

2.3 Description of Sandcrete

The composites of sandcrete have traditionally been cement, sand, and water. For example, source defined sandcrete as a yellow-white building material made from a binder, which is typically Portland cement, sand, and water. However, in some cases, other ingredients, such as rice husk ash, are added to reduce the volume of cement, or rice bran and straw are added to either improve on the binding properties or reduce the weight of sandcrete for special purposes. According to Alain et al. (2002), sandcrete is a calculated mixture of these conventional and sometimes experimental composites. Traditionally, sandcrete constitutes about one part of cement to about eight parts of sand. The strength of sandcrete had been found to weaken as the volume of sand increases, while, at the same time, the volume of cement either remains the same or reduces.

Alain et al. (2002) drew a distinction between sandcrete and mortar, defining mortar as a workable paste applied in binding building blocks, such as stones, bricks, and concrete masonry units together. While sandcrete is used to make building blocks, mortar is used in filling and sealing the gaps and irregular spaces between blocks, as well as holding these blocks together. Moreover, mortar is usually mixed at a ratio of 1:5 parts of cement and sand. Sandcrete is also different from landcrete, which refers to using soil as a total replacement of sand in sandcrete. Aguwa (2010) termed landcrete as literite-cement blocks and after a comparative test with sandcrete blocks, indicated that laterite-cement blocks perform better than sandcrete blocks, at percentage of cement content below 10 percent. Sandcrete can also be differentiated from hydraform mixtures which are used in forming earth blocks.

Sandcrete is also not the same as concrete, which is defined as a mixture of fine aggregate, cement, water, and coarse aggregate (BS 2787, 1956). Fine aggregate usually constitutes sand, which is dug or dredged from a pit, river, lake, or seabed, whereas coarse aggregate comprises crushed quarry rocks, boulders, cobbles, and large-size gravels. Sandcrete is usually used as rectangular blocks, measuring about 45cm wide, 15cm thick, and 22.5cm long. They are used as construction units, and held together by mortar (Hornbostel, 2011).

2.4 Materials for Making Sandcrete Blocks

Oyekan and Kamiyo (2008) note that sandcrete blocks contain a mixture of sand, cement and water. Sandcrete is, therefore, a composite material consisting of a binder, which is typically cement, fine aggregates, which is usually sand, as well as water, and may sometimes include admixtures, such as rice bran, straw, sawdust, coconut shells, and palm kernel shells.

2.4.1 Binders

According to Williams (2005), a binder is any adhesive material or substance that holds or draws other materials together to form a cohesive whole mechanically and chemically. In other words, a binder is a substance that can convert from paste-state to a solid state and, in the process, binds filler power/particles added into it. Source also defined binders as fine, granular materials that form a paste when water is added to them, but then hardens and encapsulates aggregates.

Williams (2005) classified binders into organic and inorganic, whereby organic binders take the form of bitumen, animal and plant glues, and polymers, and inorganic binders include lime, cement, gypsum, and resin. In sandcrete mixtures, the commonest binder is cement, either lime cement, such as Portland cement or Roman cement, as well as acid-resistant cement such as quartz cement and silicon fluoride cement (Aguwa, 2010; Kaur & Kaur, 2012; Oyekan & Kamito, 2011).

There are different types of cement, but Portland cement is the binder used most widely. ASTM-C150 (2016) defined Portland cement as water-resistant product developed by pulverizing clinkers consisting essentially of hydraulic calcium silicates, usually containing one or more of the forms of calcium sulphate. Portland cement is made by fusing calcium-bearing with aluminum-bearing materials. The calcium is usually obtained from limestone, shells, chalk, or marl, which is a soft stone, or hard mud, sometimes called mudstone, that is rich in lime.

ASTM-C150 (2016) designated five types of Portland cement, into general purpose, moderate sulphate resistance, high early resistance, high early strength, low heat of hydration, and high sulphate resistance. According to ASTM-C150 (2016), general purpose cement has fairly high calcium silicate content which is good for early strength development. They can be used for construction of buildings, bridges, pavement, precast units, and other general construction purposes. Moderate sulphate resistance cement has less than 8% of calcium aluminium content and is useful for structures exposed to soil or water containing sulphate ions. High early strength cement is needed for rapid construction and cold weather concreting, and is composed of higher calcium silicate content. The other classifications cover low heat of hydration and high sulphate resistance cement.

Mamlouk and Zaniewski (2009) observed that immediately after water is added, cement paste begins to harden through the process of hydration. When water is added to cement, each of the compounds undergoes hydration and contributes to the final sandcrete product. According to Gibbsons (2008), the strength of mixtures, such as concrete after hydration depends largely on the different properties of the binders and admixtures used, the water-to-cement ratio, and the environmental conditions under which the sandcrete is cured.

2.4.2 Aggregates in Sandcrete

Nelson and Bolen (2008) defined aggregates as granular materials which are held together by binders in sandcrete. According to Oyekan (2008), aggregates are inert granular materials such as sand, gravel, or crushed stone that, along with water and Portland cement, are an essential ingredient in concrete and sandcrete. Aggregates, such as naturally weathered gravel and sand, can be dug or dredged from a pit, river, lake, or seabed. On the other hand, aggregates can be manufactured by crushing quarry rocks, boulders, cobbles, or large-size gravel into different sizes, such as quarry dust or crushed aggregate.

2.5 PKS as a Sustainable Building Material in Ghana

As a quest for implementing affordable housing system for both the rural and urban population of Ghana and other developing countries, various proposals focusing on cutting down conventional building material costs have been put forward. One of the suggestions in the forefront has been the sourcing, development and use of alternative, non-conventional local construction materials including the possibility of using some agricultural and industrial wastes and residues (e.g. palm kernel shells) as construction materials (Tukiman and Mohd, 2009). The quality and cost effectiveness of construction materials employed in housing developments are among the major factors that determines the optimal delivery of housing projects (Akutu, 2013). Therefore, materials to be used for building construction must provide objective evidence of quality and cost effectiveness in terms of functional requirements and low income economy respectively. In view of this, the search for low-cost material that is socially acceptable and economically available, at an acceptable quantity within the reach of an ordinary man becomes a subject of continuous interest. The belief that the African region is full of raw materials suitable for local uses encourages this, yet the construction sector is not making optimal use of them (Ramachandran, 2013).

Aggregates are the most important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. Aggregates were considered as chemically inert materials but now it has been recognized that some of the aggregates are chemically active and also that certain aggregates exhibit chemical bound at the interface of aggregate and paste. For the fact that the aggregates occupy 70 – 80 per cent of the value of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable. Its physical, thermal and chemical properties influence the performance of concrete to a great extent and provide better strength, stability and durability to the structure made from cement concrete than cement paste alone. To know more about the concrete, it is very essential that one should know more about the aggregates which constitutes major volume in concrete. Since other ingredients namely water and aggregates are natural materials and can vary to any extent in many of their properties, hence the need for in depth range of studies that are required to be made in respect of aggregates to understand their widely varying effect and influence on the properties of concrete cannot be underrated.

Classification of Aggregates The classification of the aggregates is generally based on their geological origin, size and unit weight.

Classification according to geological origin: The aggregates are usually derived from natural sources and may have been naturally reduced to size (e.g. gravel or shingle) or may have to be reduced by crushing. This type of aggregates can be further sub-divided to natural and artificial aggregates. Examples of natural aggregates are aggregates obtained from natural deposits of Sand and gravel or from quarries by cutting rocks. While the examples of artificial aggregate are clear broken bricks and air cooled fresh blast furnace–slag.

Classification according to size: According to size the aggregate is classified as fine aggregate, coarse aggregate and all in-aggregate. The maximum size of the aggregate may vary, but in each case it is to be so graded that the particle of different size fractions are incorporated in the mix in appropriate proportions.

Classification according to shape: It was reported by Gambir (2005) that the particle shapes of aggregates influence the properties of fresh concrete more than those of hardened concrete. Depending upon the particle shape the aggregate may be classified as rounded, irregular or partly round, angular or flaky.

Flaky and elongated aggregates: An aggregate is termed flaky when its least dimension (thickness) is less than three-fifth of its mean dimension. The main dimension of the aggregate is the average of the sieve size through which the particles pass and are retained respectively. An aggregate is said to be elongated when its greatest dimension (length) is greater than nine-fifth of its main dimension.

Classification based on unit weight: The aggregates can also be classified according to their unit weights as normal weight, heavy weight and light weight aggregates.

Light Weight Aggregate The light weight aggregates having unit weight up to 12KN/m3 and used in the manufacturing of structural concrete and masonry block for reduction of the self-weight of the structure. These aggregates can be either natural such as diatomite, pumice, volcanic cinder or manufactured, such as bloated clays, sintered fly ash or foamed blast furnace slay. In addition to reduction in the weight, the concrete produced by using light weight aggregate provides better thermal insulation and improved fire resistance. Light weight aggregates may be grouped in the following categories:

i) Naturally occurring materials which require further processing, such as y, shale and slate, etc. ii) Industrial by-products, such as sintered pulverized fuel ash (fly ash), foamed or expanded blast-furnace slag.

iii) Naturally occurring materials, such as pumice, foamed lava, volcanic and porous limestone.

Aggregates can also take the form of recycled concrete, which are crushed used in granular sub-bases, soil-cement, and in new concrete (Wilburn & Goonan, 2008). Nelson and Bolen (2008) acknowledged that usually, aggregates would require some processing after harvesting from source. These may include crushing, screening, and washing in order to obtain the required cleanliness and gradation. In some cases, a benefaction process such as jigging or heavy media separation can be used to upgrade the quality, by extracting gypsum and other unwanted metallic components from the recycled aggregates.

According to the Concrete Centre (2010), there are two forms of aggregates, namely coarse and fine aggregates. Coarse aggregates refer to any particles in the sandcrete or concrete mixture that is larger than 4.83mm, but generally range between 9.53mm and 38.1mm in diameter. Coarse aggregates are usually added to concrete mixtures, of which gravel constitutes the majority and the remainder usually consisting of crushed stone or granite. The Concrete Centre (2010) also indicated that coarse aggregates refer to stones that are retained on 4.75mm (0.187inch) sieve. The Concrete Centre (2010) described fine aggregates as generally consisting of natural sand or crushed stone with most particles passing through 0.375 inch sieve. In other words, fine aggregates will pass a No. 4 sieve and will, for the most part, be retained on a No. 75µm sieve.

Siddique (2004) observed that aggregates help reduce sandcrete costs because they are less expensive than cement paste. The purpose of the fine aggregate is to fill the voids in the coarse aggregate and to act as a workability agent. According to Malhotra (2005), the properties of aggregates, such as shape and size, can have a significant effect on the workability of concrete in its plastic state, as well as the durability, strength, density, and thermal properties of the hardened concrete. For example by partially replacing sand with granite coarse aggregate brought about an appreciable increase in the 28-day compressive strength of sandcrete blocks, in a study conducted by Oyekan (2008).

According to the National Nuclear Security Administration (2009), the shape of aggregates and their surface texture influence the properties of sandcrete and concrete. Moreover, rough-textured, angular, and elongated particles require more water to produce workable concrete than smooth, rounded compact aggregate. They also found that different minerals in the aggregate wear and polish at different rates, whereas harder aggregate are useful in highly abrasive conditions, where minimizing wear is a primary objective.

There are different types of fine aggregates depending on the origin of the sand. Sand, which is the commonest type of fine aggregate are made up of little particles of silica obtained from silt or clay, whereas larger particles are labeled as gravel. A distinction can be made between pit sand and river or sea sand. Pit sand is obtained from pits, whereas river sand is dredged from river or sea beds. Sand obtained from the banks and beds of rivers can also be classified as either fine or coarse. Stone dust is another kind of fine aggregate usually used in building blocks in place of sand or in partial replacement of sand. Stone dust is obtained from finely crushed stones such as quarry rocks, in which case the aggregate is referred to as quarry dust. Cinder, which is granulated coal or granulated igneous rock, has also been used as aggregates in building blocks.

The discussion shows that aggregates are obtained from bedrock, which includes igneous, sedimentary and metamorphic rocks. The properties of the aggregates are therefore defined by the characteristics of the parent rock and the manufactured block. For example, sources found that partial replacement of sand with rice husks as well as total replacement of sands with quarry dust reduced the mechanical properties of blocks, whereas partial replacement of sand with quarry dust improved the mechanical properties of building blocks. On the other hand, Gebler (2006), Atis (2002), Malhotra (2005), and Siddique (2004), demonstrated that mechanical properties of blocks were more influenced by finishing and curing of blocks irrespective of their aggregates.

2.6 Admixtures in Sandcrete

In some cases, admixtures, such as corn cob ash and peanut shell ash (Nimityongskul & Daladar, 2015), coconut husks (Oyelade, 2011), sawdust (Adebakin et al., 2012; Boob, 2014), as well as rice husks (Michael, 2014; Oyetola & Abdullahi, 2006), may be included in sandcrete to control mechanical properties. Studies have found that different chemical reactions occur in the sandcrete mixture based on the differences in the individual properties of constituent materials, which are combined (Aguwa, 2010; Gibson, 2008). These same studies have observed that the materials, can vary in their chemical composition and performance characteristics, depending on where their sources, the variations in manufacturing methods, and the conditions in the manufacturing plant. For example, Oyelade (2011) found that replacement of cement with coconut husk ash in the production of sandcrete blocks reduced the mechanical strength of the blocks.

Sureshchandra et al. (2014) also found that partial replacement of sand with quarry dust in sandcrete blocks enhanced performance as compared to total replacement of sand in sandcrete.

2.7 Lightweight Aggregates

According to Chandra and Berntsson (2002), lightweight aggregate has been used since ancient times. The fact that some of these structures are still in good condition validates the durability of concrete (Chandra & Berntsson, 2002). Lightweight aggregate is any aggregate with a particle density of less than 2.0kg/m^3 or dry loose bulk density of less than 1200kg/m^3. Suitable aggregate require low cement paste content in structural concrete and having low water absorption (BS EN 13055).

Neville and Brooks (2008) sub-categorized lightweight aggregates into naturally occurring and manufactured aggregates. They established that the major natural lightweight aggregates are diatomite, pumice, scoria, volcanic cinders and tuff. Manufactured aggregates can also take the form of naturally occurring materials, such as expanded clay, shale, slate, perlite and vermiculite that require further processing through heating. Lightweight aggregates also include industrial by-products such as sintered pulverized-fuel ash (fly ash), sintered slate and colliery waste, foamed or expanded blast-furnace slag (Cement and Coarse Aggregate Australia, 2008). Owing to the cost of obtaining and processing conventional lightweight, alternative lightweight aggregates, especially in tropical countries are looking into coconut ash, palm kernel shells, and rice husks.

The research into lightweight palm kernel shell aggregate has been pursued as far back as the 1980s. Early studies including Abdullah (2014) and Okafor (2008) found that

PKS as lightweight aggregate produced compressive strength in the range of 15-25 MPa. Generally, however, the mechanical properties of Palm Kernel Shell concrete depend on factors such as cement, water, sand and aggregate contents and density. Oyejobi et al. (2012) proved this by comparing three mixes of sand, PKS, and cement, in ratios, of 1:3:6, 1:4:8, and 1:1.5:3 at 28 days of curing. They found that concrete made with nominal mixes of 1:3:6 and 1:4:8 generally gave poor results than those with mixes of 1:1.5:3 at 28 days curing.

Alain et al. (2002) established that, in order to achieve a high compressive strength of PKS-sandcrete blocks of about 4.6N.mm^2, the bond between mortar and PKS has to be improved. In terms of lightweight sandcrete, some studies found that adding silica fume as partial replacement of cement increases the strength properties of sandcrete. Katkhuda et al. (2009) found that the optimum compressive strength, flexure strength, and split tensile strength of lightweight sandcrete were at water-cement ratio of 0.26 and 15% replacement of cement with silica fumes. Yew, Mahmud, Ang, and Yew (2014) found that older PKS (between 10 to 15 years old) produce concrete with higher compressive strength, but adding silica fumes also increases the compressive strength, reduces permeability, and improves aggregate-cement paste interface. Source however noted that the use of these fine materials, such as silica fumes in lightweight sandcrete demands more water to maintain workability and they achieve comparable strengths only when used with super plasticizing admixtures. The SiO_2 from the Silica Fume particles reacts with the liberated calcium hydroxide from cement hydration to produce calcium silicate and alumina hydrates. This reaction increases the strength and reduces the permeability by making the concrete dense (Neville, 2006; Robert et al., 2003).

2.8 Description of Palm Kernel Shells

An oil palm fruit consists of the palm nut, the shell, and the mesocarp. When the mesocarp and the nut are separated from the palm fruit through cyclone separation, the remaining shell is termed as the palm kernel shell or PKS. Olutoge (2015) also described PKS as the hard endocarp of palm kernel fruit that surrounds the palm seed, and that it is obtained as crushed pieces after threshing or crushing to remove the seed which is used in the production of palm kernel oil. Palm kernel shell (PKS) is therefore the by-product from palm oil industry, where the mesocarp is used for producing crude palm oil and the nuts are used for manufacturing palm kernel oil. Zafar (2015) also described PKS as fibrous material which are mixed in large and small shell fractions, including dust-like fractions. However, Alengaram, et al. (2010) noted that the useful part of PKS which is applicable as lightweight aggregate in concrete mix is obtained after removing the dust and fibres.

2.8.1 Types of palm kernel shells

Palm kernel shells are obtained from two main types of palm fruits, namely Tenera and Dura. Generally, the dura has a larger kernels and thinner fruit fibre. According to Acquah (2010), the dura consists of a thick pericarp 2 to 8mm thick, a thin mesocarp, averagely about content is 35 to 55 percent of the total fruit content. The thicker shell and generally large kernels makes it less desirable for palm oil producers, but more suitable for kernel oil production. The tenera species, on the other hand, possesses a thicker mesocarp, thin endocarp and a reasonably sized kernel. This variety of oil palm is more useful in the production of oil palm, given its thicker pulp, but less kernel oil when compared with the dura variety. Acquah (2010) argues that, palm oil production in Ghana has been the main aim of oil palm plantations and thus, the tenera variety is the more favoured by cultivators.

2.8.2 Preparation of palm kernel shell as coarse aggregate

Preparing PKS as coarse aggregates involves two major processes, namely cracking and lab preparation (Koya & Faborode, 2006). Depending on factors, such as quantity of shells needed and the availability of mechanical tools for cracking, the cracking of the palm nut can be done manually or mechanically. Manual cracking is employed when small quantity of palm kernel is needed (Koya & Olufemi, 2006). The method involves heaping the nuts and people sit to crack them with stones. After the cracking, the crackers hand picks the shells from the kernel.

Studies have shown that the separation of the kernel and the shells could also be done by floating method. In the floating method, clay is mixed with water in a tank. The cracked nuts are added to the mixture. Since the shells are denser than the kernel, they settle with the clay while the kernels float. The picking of the kernels is done by stirring the mixture intermittently to bring up the kernels trapped by the clay. In this the clay coats both the shells and the kernels which would need washing before using them (Koya & Faborode, 2006; Koya & Olufemi, 2006; Andoh, Agyare & Dadzie, 2010). The mechanical cracking involves cracking the palm nuts with a machine. Ideally, the machines which do the cracking also do the separation simultaneously. However, Andoh et al. (2010) indicated that in Ghana, handpicking is also used to separate the kernel from the shells after mechanically cracking the nits.

The lab preparation of Palm Kernel Shell involves drying, sieving and washing the aggregates with detergents in order to remove dust, oil and mud particles that adhered to the surfaces of Palm Kernel Shell. After washing, the shells are air dried and then stockpiled. Due to the high water absorption of Palm Kernel Shell (about 25%), pre-soaking of aggregates for about 45 min to 1 hour is mandatory. The absorption during this period of pre-soaking is determined and finds to be in the range of 10 to 12%. Particles with size less than 3.35 mm were removed and not used in mixes due to large relative surface area and high absorption.

2.8.3 Physical properties of palm kernel shells

Owolarafe et-al (2007) noted that the physical properties of palm kernel shells as size, shape, spherical, aspect ratio, true density, bulk density and porosity, and mechanical properties such as coefficient of friction angle of repose as well as fracture resistance are very important for construction purposes. They indicated that these factors potentially affect the bonding properties and weight of the final cubes of blocks. Thus, it is essential to understand the potential influence of these properties on the sandcrete cubes. The subsequent sections therefore discusses the physical properties of palm kernels shells and present different studies to show the variety of effects of these properties on moulding blocks with palm kernel shells.

According to Mohammed et al. (2014), the physical characteristics of palm kernel shells (PKS) are similar to coarse aggregates used in block moulding. They also noted that PKS are one of the wastes produced during processing of palm oil. Their colour ranges from dark grey to black. The shells are of different shapes, such as angular and polygonal depending on the breaking pattern of the nut. The surfaces of the shells are fairly smooth for both concave and convex faces. However, the broken edge is rough and spiky. Emiero and Oyedepo (2012) held the view that the smooth, as well as concave and convex surfaces of palm kernel shells are likely to affect the bond matrix with cement.

Studies including, Okafor (2008), Okpala (2010) and Basri et al., (2009), Abdullah (2003), Addai and Musa (2010), Mohammed et al. (2014), Dadzie and Yankah (2015) have made attempts to use Palm Kernel Shells as coarse aggregates replacing normal coarse aggregates traditionally used for construction purposes, such as asphaltic concrete, building concrete, and sancrete. Okafor (2008), Okpala (2010), Dadzie and Yankah (2015) found that the specific gravity of Palm Kernel Shells varies between 1.17 and 1.37. On the other hand, Olutoge et al. (2012) found that the specific gravity of PKS ranged from 2.18 to 2.41, whereas Olutaiwo and Owolabi (2015) found that the specific gravity of PKS of mixed proportions was 1.62.

The thickness of PKS varies and depends on the species of palm tree from which the palm nut is obtained and ranges from 0.15 to 8mm while the maximum thickness of the shell was found to be about 4mm (Basri et al., 2009; Okpala, 2010). The thickness of PKS changes according to their absorption capacity. Neville (2008) found that PKS have a 24 hour water absorption capacity range of 21 to 33 percent. Dadzie and Yankah (2015) confirmed this as they found that that PKS have a 24 hour water absorption capacity of 25 percent. On the other hand, Dagwa and Ibhadode (2008) found that PKS have a mean water absorption capacity of 19.85 ± 2.065%, indicating that the minimum water absorption capacity of PKS can be lower than 21 percent. They also found that the thickness swell in water of PKS is 3.54%, their oil absorption capacity is 6.845 ± 0.175%, and their thickness swell in oil is averagely 2.33%. These values implied that PKS generally have higher water absorption compared to conventional coarse aggregates, such as gravel and sand that usually have water absorption of less than 2 percent (Neville, 2008).

Several studies have indicated that PKS have high water absorption due to their high porosity. The porosity of the PKS, according to Okpala (2010) averages at 37%. Basri et al. (2009) found that because of the higher porosity of PKS, in comparison with conventional aggregates, their loose and compacted bulk densities from about 500 to 550 and 590 to 620 kg/m^3, respectively. In another study, Mak et al. (2009) also established that PKS are predominantly micro porous materials, where micropores account 68–79% of total porosity. Okroigwe et al. (2014) found that the porosity of PKS was 28% with a bulk density of 740 kg/m^3. From studies including Okpala (2010), Basri et al. (2009), and Okroigwe et al. (2014), it was noted that the bulk density of PKS can range from 590 to 740 kg/m^3, whereas their porosity can range from 28% to 37%. These ranges of densities show that palm kernel shells are approximately 60% lighter than conventional coarse aggregates. The densities of the shell are within the range of most typical lightweight aggregates (Okpala, 2010; Okafor, 2008).

Okroigwe et al. (2014) maintained that PKS is high in lignin, hemicelluloses, and silica-containing ash, which makes them prone to forming particulate matter during combustion. This is because the chemical components of PKS have large heating values. PKS therefore has a high heating value and are resistant to fires. The ASTM (1978) indicated that PKS is a virgin biomass with a high calorific value, typically about 3,800 Kcal/kg, whereas palmshell.com (2016) reports that the gross calorific value of palm kernel shells is as high as 5,200kWh/MT (4,474.187 Kcal/kg or 18.80 GJ/MT). Schobert

(1995) found the calorific value of sand to be 17 MJ/kg. Thus, PKS adapts better to heat than sand, and this is expected to transition into its usage in sandcrete blocks.

The Los Angeles abrasion value of the PKS and crushed stone was reported as 4.8 and 24% respectively. Alengaram et al. (2012) also reported that the range of abrasion values for PKS aggregate is 3–8% whereas that of crushed stone is about 20–25%. This shows that it is much lower than conventional coarse aggregates and has a good resistance to wear (Basri et al., 2009, Los Angeles Abrasion, 2012).

Mannan et al. (2006) reported an improvement in the quality of palm kernel shells by using pre-treatment methods such as 20% poly vinyl alcohol as a PVA solution. This decreased the water absorption of palm kernel shells significantly from 23.3 to 4.2%. Furthermore, the aggregate impact value and aggregate crushing value of palm kernel shells aggregates were much lower as compared to conventional crushed stone aggregates. This shows that palm kernel shells aggregate has a good absorbance to shock (Teo et al., 2007). Okpala (2010) reported that the indirect compressive strength test of palm kernel shells aggregate was 12.10MPa with a standard deviation of about 2MPa.

2.8.4 Size of palm kernel shells needed to obtain standard brick strength

The properties of aggregates have implications for the bonding properties of concrete mixtures (Adedeji & Ajayi, 2008). One of the most significant properties is the size of aggregates. In this wise, some studies have investigated the effects of different particle size of coarse aggregates on cement mixtures.

Zang, Liu, and Wang (2005) investigated the effects of coarse aggregates size on relationship between stress and crack opening in normal and high strength concretes. Their central research question was formed around the idea that while fine and coarse aggregates play an important role in the fracture of concrete, quantitative information available on the effect of the coarse aggregate size on the fracture properties of concrete is still limited. They experimented with coarse aggregate size's (single grade of 5~10, 10~16, 16~20 and 20~25 mm) effect on stress-crack opening (σ-w) relation in normal concrete (compressive strength of 40 MPa) and high strength concrete (compressive strength of 80 MPa).

Zang *et al.* (2005) experiment was based on three-point bending tests implemented by fictitious crack analysis. The result showed that for a given total aggregate content, in normal strength concrete, smaller size of aggregate leads to a high tensile strength and a sharp stress drop after the peak stress. The smaller the coarse aggregate, the steeper the σ-w curve. By contrast, in high strength concrete, the effect of aggregate size on σ-w relation almost vanishes. A similar σ-w relation is obtained for the concrete except for the case of 20~25 mm coarse aggregate size. The stress drop after the peak stress is more significant for high strength concrete than that for normal strength concrete. Meanwhile, the smaller the coarse aggregate size, the higher the flexural strength. Fracture energy and characteristic length increase with increasing coarse aggregate size in both normal and high strength concretes.

Yaqub and Bukhari (2006) also studied the influence of aggregate size on the compressive strength of high strength concrete. High strength concrete is a type of high performance concrete generally with a specified compressive strength of 40 Mpa (6000psi) or greater. They carried out an experimental program in University of Engineering and Technology, Taxila, Pakistan. Five different sizes of course aggregates, 37.5mm, 25mm, 20mm, 10mm and 5 mm, were used while developing a mix design.

Natural sand with fineness modules of 3.48 was used as fine aggregate. Ordinary Portland cement was used as binding material. Different trials of mixing of coarse aggregate were made (37.5mm and 25mm, 25 mm and 20mm, 20mm and 10mm, 10mm and 5mm) to investigate the influence of size of aggregate on compressive strength of concrete. Cylinders of size 150mmx300mm were cast in laboratory and tested in Universal compression testing machine. It was concluded that 10mm and 5mm aggregates showed higher compressive strength than other types of aggregates.

Ajamu and Ige (2015) noted that concrete structures deflect, crack, and loose stiffness when subjected to external load. They therefore investigated the effect of varying coarse aggregate size on the flexural and compressive strengths of concrete beam. Concrete cubes and beams were produced in accordance with BS 1881-108 (1983) and ASTM C293 with varying aggregate sizes 9.0mm, 13.2mm, 19mm, 25.0mm and 37.5mm, using a standard mould of internal dimension 150x150x150mm for the concrete cubes and a mould of internal dimension of 150 x 150 x 750mm for the reinforced concrete beam. The water cement ratio was kept at 0.65 with a mix proportion of 1:2:4. The specimen produced were all subjected to curing in water for 28days and were all tested to determine the compressive strength and flexural strength using Universal Testing Machine. Compressive strength of cubes was 21.26N/mm^2, 23.41N/mm^2, 23.66N/mm^2, and 24.31N/mm^2 for coarse aggregate sizes 13.2mm, 19mm, 25.0mm and 37.5mm respectively. That of flexural strength of test beams is 4.93N/mm^2, 4.78N/mm^2, 4.53N/mm^2, 4.49N/mm^2, 4.40N/mm^2 respectively.

Olusola and Babefemi (2013) conducted an investigation into the effect of coarse aggregate size and replacement level of granite with palm kernel shell (PKS) on the compressive and tensile strengths of PKS concrete were investigated. The coarse aggregates, PKS and granite, were graded into three maximum coarse aggregate sizes, passing through 10mm, 14mm, and 20mm, but retained on 5mm BS sieve. A mix proportion by mass of 1:1½:2 was used for this work with a water/cement ratio of 0.50. PKS was used to replace granite in steps of 25% from 0-100% in the mix to study the effect of proportions, while the three maximum coarse aggregate sizes were used to study its influence on PKS concrete. All samples were tested at 7 and up to 90 days.

Olusola and Babefemi's (2013) results showed that both compressive and splitting tensile strengths increased with increase in aggregate sizes. Both strengths however decreased with increase in replacement levels of granite with PKS. Optimum replacement level of granite with PKS was 25% with compressive and tensile strengths of 22.97 N/mm2 and 1.89 N/mm2, respectively at maximum coarse aggregate size of 20 mm. However, at 50% PKS content, which results in light weight concrete, compressive strength was 18.13 N/mm2, which is above the minimum value of 17MPa for lightweight concrete.

Woode et al. (2015) conducted their study to determine the effect of different sizes of machine crushed gneisses used in Ghana for concrete production on the compressive strength of concrete. Coarse aggregate samples of maximum sizes of 10mm, 14mm and 20mm were used to produce concrete at constant water/cement ratio of 0.63. In all the experiments, the concreting procedures and materials were kept constant whiles the maximum coarse aggregate sizes were varied. A total of 36 concrete cubes were crushed at 7, 14, 21 and 28 days to determine their compressive strengths.

Woode *et al.* (2015) study showed that the smallest coarse aggregate size gave the highest compressive strength and lowest slump at constant water/cement ratio. A regression analysis also shows that the relationship between the maximum coarse aggregate size and the compressive strength follows a polynomial with $R^2 = 1$; indicating that the model is reliable. The optimum maximum coarse aggregate size for the best compressive strength of 28 day concrete was therefore found to be 8mm for the water/cement ratio of 0.63. The analysis further indicated that as heterogeneity increases the compressive strength of concrete reduces.

2.8.5 Volume of PKS replacement for optimum strength

Muntohar and Rahman (2014) made an experimental study on the development of the shellcrete masonry block that made use of palm kernel shell (PKS). The masonry block was called shellcrete. The study focused on the physical, compressive and flexural strengths of shellcrete. The shellcrete was made by mixing the Portland cement (PC), sand, and oil palm kernel shell (PKS). A control specimen made of PC and sand mixture (sandcrete) was also prepared. The maximum strength obtained was 22MPa by mixing proportion of 1 PC:1 Sand:1 PKS, but the recommended mix proportion of the shellcrete for building materials was 1 PC:1 Sand:2 PKS as an optimum mix design for eco friendly shellcrete. The best mix design was 1:1:2 (OPC: sand: PKS). The study revealed that the shellcrete was acceptable for lightweight materials and masonry block

As part of Olutoge's (2010) study, he investigated the use of palm kernel shells (PKS) as replacement for fine and coarse aggregates in reinforced concrete slabs. Reinforced concrete slabs measuring 800 x 300 x 75mm were cast. PKS were used to replace both fine and coarse aggregates from 0% to 100% in steps of 25%. Flexural strengths were evaluated at 7, 14 and 28 days and compressive strengths were evaluated at 28 days as shown in Table 2.1. Olutoge (2010) found that increase in percentage of palm kernel shells in concrete slabs led to a corresponding reduction in both flexural and compressive strength values. The study found that at a low replacement value of 25% PKS can produce lightweight reinforced concrete slabs which could be used where low stress is required at reduced cost. A weight reduction 17.9% was achieved for PKS replacement slabs.

Table 2.1 Flexural and compressive strength of slabs with various percentages of palm kernel shells

	7 days		14 days		28 days		
% PKS	Weight (kg)	Flexural strength (N/mm2)	Weight (kg)	Flexural strength (N/mm2)	Weight (kg)	Flexural strength (N/mm2)	Comp. strength (N/mm2)
0	40.95	1.43	40.80	1.96	41.10	2.24	21.6
25	32.66	1.19	35.41	1.35	33.75	1.75	15.9
50	31.44	1.19	30.16	1.18	31.73	1.19	10.9
75	29.22	0.80	27.55	0.81	30.63	0.87	8.5
100	28.01	0.68	26.87	0.70	28.93	0.75	7.2

Source: Olutoge, 2010

Dadzie and Yankah (2015) explored and compared the properties of masonry blocks produced with palm kernel shell (PKS) as partial replacement to the traditional sandcrete blocks in an attempt to establish the percentage replacement of PKS that yields properties and characteristics that meets acceptable standards. They batched their samples by a mix proportion of (1:6). The PKS replacement varies from 0%, 10%, 20%, 30%, 40% and 50% with water cement ratio of 0.5. Total of 24 blocks were moulded, cured for

28days, subjected to various tests including water absorption, weight, density, and compressive strength. With regard to strength test, they found that the compressive strength of the PKS blocks exceeds the minimum requirement of 2.8N/mm2 when the PKS replacement do not exceeds 40%.

Olutaiwo and Owolabi (2015) evaluated the effect of partial replacement of coarse aggregate (4-8mm crushed stone) with graded palm kernel shell in asphaltic wearing course. They evaluated the volumetric and physical properties of the asphalt mixtures in order to determine the performance characteristics of PKS in the mass production of wearing course asphalt concrete for medium traffic road. Percentages of PKS used were 0%, 30%, 50%, 70% and 100%. Specifically, 15 samples for control mix and 60 samples for the PKS proportions of compacted asphalt mixtures were prepared by using Marshall mixing procedure. The samples were prepared by varying bitumen contents from 5.0% to 7.0% in an increment of 0.5% and tested using the Marshall method. The results indicated that the mixture at 30% PKS meets the criteria provided in the Asphalt Institute Standard Specification. It was observed that for medium trafficked roads, graded palm kernel shells between 10%-30% by weight of coarse aggregate (4-8mm crushed stone) can be used for the replacement while even 100% replacement is possible for lightly trafficked rural roads.

In the empirical studies it was noted that in each of the cases where coarse aggregates were replaced by PKS, the strength of the blocks reduced in comparison with regular concrete (Olutoge, 2010), sandcrete (Dadzie & Yankah, 2015), and even asphaltic mixtures (Olutaiwo & Owolabi, 2015). In all cases, the strength of the mixtures reduced further, as the percentage of PKS in the mixtures increased. The studies indicated that the optimum replacement level of coarse aggregate is 25% (Olutoge, 2010) but should not exceed 40% (Dadzie & Yankah, 2015)

2.8.6 Water absorption and abrasion properties of PKS bricks

Water can enter the pores in the cement paste and even in the aggregate, and this weakens the slabs of masonry block when prolonged. One of the most important properties of a good quality masonry block is, therefore, low permeability (ASTM-C140, 2000). Low permeability means that the masonry unit can resist ingress of water and is not as susceptible to freezing and thawing (ASTM-C140, 2000). Low resistance to water permeation is important for reducing cracks, foliation, and structural deformation. Some studies have investigated the water absorption properties of blocks made with PKS.

In Olanipekun et al.'s (2006) study, they reported that the percentage water absorption increases with increase in the percentage replacement level of coarse aggregate with PKS. For mix ratio 1:1:2, the value range from 0.41% to 5.88% for PKS concrete (10% to 100% replacement levels). Teo et al. (2007) also found that the water absorption of PKS concrete under air drying curing and full water curing were 11.23% and 10.64% respectively.

Ohemeng et al. (2015) conducted a study which partly analysed water absorption of blocks made with PKS. They found that the water absorption increases as the percentage of the palm kernel aggregate rises. The water absorption moved from 1.46% to 1.77%, indicating a rise of about 21% when 60% of the sand was substituted with PKS aggregates. It can be noticed that the water absorption values found in this study are within that of normal weight concrete. They found that a linear relationship between palm kernel content and percentage increase in water absorption. The R^2 of 0.9962 indicated that 99.62% of the variation in water absorption can be explained by palm kernel shell content.

Ekong (2015) also carried out water absorption tests on PKS particle sizes graded into 1mm, 2mm, 3mm and 4mm. Water absorption tests were carried out for each grade of PKS. Water absorption test was performed by a 24 hour immersion in cold water. A known mass of 20g of each particle grade of PKS was preconditioned by drying in a test kiln at 110ºC. This was to ensure total water loss in the samples. After they were allowed to cool at room temperature, each particle grade was weighed and the dry (initial) mass was recorded. Each of the preconditioned particle grades was immersed in cold water and allowed for 24 hours in room temperature. Thereafter, the samples were collected in a 75 micron mesh. This was in order to get rid of excess water. The residue was weighed and the new mass recorded against the initial mass. The percentage water absorption for each sample was then calculated using the formula: Mass of water absorbed x 100 /Initial mass of substance (PKS)

The study found that PKS does not absorb water above 45%. The 1mm grade which absorbs water above 45% is enhanced by its high fibre contents. Fibre was high in the grade because they could not pass through the mesh. The 2mm grade which had about the most ideal water absorption had just 10%, while 3mm and 4mm grades had 25% each. The water absorption tests showed low percentage absorbency. The high absorption rate obtained from 1mm grade of palm kernel shells is, perhaps, due to its fibre content since this was not present in other grades.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter deals with the methodological approach used for the study. It elaborates on the study design, the materials and methods used, as well as the data collected for the study. The test procedures are also elaborated along with the methods used to analyze the data.

3.2 Materials

This section describes the materials used in the experiments. They are described in terms of their sources, measurements, and physical characteristics.

3.2.1 Cement

Ordinary Portland cement of grade 42.5 was used for the experiment. The brand used was Dangote cement. This brand of cement gives a finer finish to sandrete works. Additionally, the mixed cement has fewer air-pockets and therefore adheres better and has a longer life.

3.2.2 Palm Kernel Shell-PKS

The palm kernel shells used were obtained from Nerebehi in the Atwima Nwabiagya District of the Ashanti Region Ghana.

3.2.3 Sand

Pit sand was obtained at the Sunyani Polytechnic premises for the experiment. Field test method was conducted to determine the amount of silt in the sand.

3.3 Methods

3.3.1 Silt Test

The sand used for the study was tested to determine the amount of silt in it using the field settlement method. The test was done according to BS 1377-2:1990 clause 8.2 and IS: 2386 (Part II).

An amount of sand for the experiment was fetched and placed in a test tube to determine the amount of silt in the sand. The sand level in the test tube was noted down. A salt solution was made and was thoroughly mixed up with the sand in the test tube. The test tube was vigorously shaken and was left to settle. After 2 hours the sand settled at the bottom of the test tube and the amount of silt in it also settled at the top of the sand. The silt and sand levels were noted and the initial level of the sand was taken from this final reading to know the level of silt in the sand. The result obtained was less than the allowable 4% (BS-882, 1992). See (plate 1).

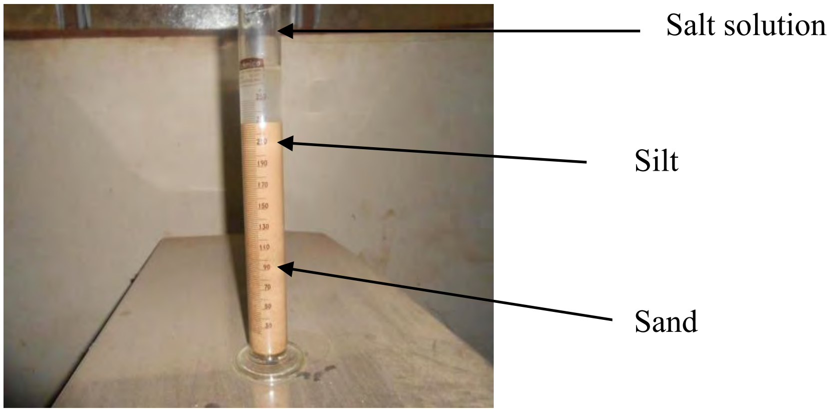

Plate 1: Silt test

3.3.2 Preparation of the palm kernel shell

Two sacks of the palm kernel shells were collected and thoroughly washed to remove all impurities and other unwanted materials.

The palm kernel shells were then allowed to be dried in the sun on a clean dry surface. (See Plate 2).

Plate 2: Drying palm kernel shells

3.3.3 Milling process

After the drying period the palm kernel shells were gathered and sent to the corn mill for grinding. The shells were placed in the funnel of the corn mill and then grinded to granular sizes (see plate 3).

Plate 3: PKS in corn mill funnel

The grinded PKS were bagged and transported to Kumasi Polytechnic where different sieve sizes were used to sieve the content.

3.3.4 Sieving

The required PKS sizes for the experiment were 1.18mm, 2.36mm and 4.75mm and thus, the 1.18mm, 2.36mm and the 4.75mm sieves (plate 4) were used to sieve the content to get the various grades. The various sieve sizes were placed on the electric shaker (plate 5) to sieve the granular PKS to the various sizes required (plate 6). The contents that were able to pass through the various sieve sizes were collected and bagged separately and labeled as 1.18mm, 2.36mm and 4.75mm respectively. They were then transported to Sunyani Polytechnic where all the experiments were conducted.

Plate 4: Sieves

Plate 5: Sieving PKS on an electric shaker

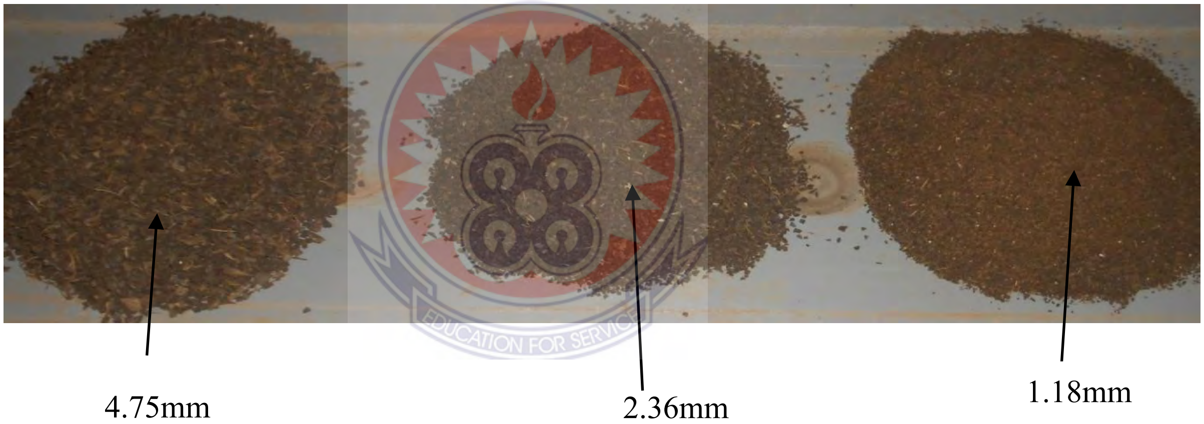

Plate 6: The various granular sizes

3.3.5 Sample size

Total samples of 150 specimens were moulded for the study. There were fifteen (15) specimens in each group.

Five experiments were conducted, and in each case three samples were required from each category. Therefore for each group of bricks, a minimum of 15 specimens were required for the experiments. The groupings included the controlled-group, sandcrete bricks with 1.88mm granular replacement 10%, 20%, and 30% of sand, sandcrete bricks with 2.36mm granular PKS replacement 10%, 20%, and 30% of sand, as well as sandcrete bricks with 4.75mm granular PKS replacement 10%, 20%, and 30% of sand. In all, a minimum population of 150 bricks was required for the experiments.

3.3.6 Batching

A trial batching was therefore done for the controlled group first in order to know the right quantity of materials to use. The batching ratio of cement to sand for the experiment was 1:3 and the cement water ratio used was 0.4. Batching was done by weight so all the materials involved were weighed on the electric weighing machine. The weight of the cement and water were constant throughout the experiment for all the categories except the sand which was varied and replaced by granular PKS of different granular sizes.

For a sample of 15 bricks, the quantity of materials used for the controlled group are presented in Table 3.1

Table 3.1 Weight of Materials for the Controlled Group

Materials	Weight (g)
Cement	12400
Sand	37200
Water	4960

Based on the trial batch, the various quantities needed for the study were weighed and are presented in Table 3.2

Table 3.2 Quantity of materials batched for the experiment

Sample	PKS Size(mm)	(%)	Cement(g)	Sand(g)	PKS(g)	Water(g)
1	Control group	0	12400	37200		4960
2	1.18	10	12400	33480	3720	4960
		20	12400	29760	7440	4960
		30	12400	26040	11160	4960
3	2.36	10	12400	33480	3720	4960
		20	12400	29760	7440	4960
		30	12400	26040	11160	4960
4	4.75	10	12400	33480	3720	4960
		20	12400	29760	7440	4960
		30	12400	26040	11160	4960

3.3.7 The mixing procedure

The mixing procedure was done manually with a hand trowel in a mixing bowl (See plate 7). The batched sand was placed in the mixing bowl and the amount of cement batched was also added and mixed with the sand thoroughly. The required amount of water was also sprinkled on the mixture and thoroughly mixed up until a uniform colour and paste was obtained for the controlled group.

Plate 7: Mixing of mortar

In the next mixing the amount of sand was reduced by percentages and was replaced by granular PKS at the same percentages. The sand and the cement were mixed up first and the quantity of granular PKS required for the replacement of sand in each category was also batched and added to the mixture and then was thoroughly mixed up. The corresponding amount of water required was also measured and sprinkled over the mixture. It was then turned several times to obtain a uniform colour.

3.3.8 Moulding of the bricks

The moulding was done using the manual moulding machine. The machine can mould four bricks (4) at a time and the brick size moulded was 215 X 102.5 X 65mm. The moulding machine was prepared and the pallets and dividers were well arranged in the moulding machine. A little amount of water was sprinkled in the machine to avoid the mixture sticking to the machine.

The controlled group was moulded first followed by replacement of sand with PKS. The mixture was fetched into the moulding machine. The tamping rod was used to tamp the mixture in the machine and additional mixture was added to it. The upper arm of the machine was used to hit the mixture in the machine for 15 times and was well moulded into the bricks. The lever of the machine was pressed down to bring up the moulded bricks out. The dividers were removed and the pallet was lifted with the bricks and then placed in a safe prepared surface for drying to take place.

3.3.9 Curing of specimens

After the moulding, all the samples were left in the open air for 24 hours. After the 24 hours some of the samples were immersed fully into a water tank for wet curing to take place (See plate 8). The rest were left in the open air for dry curing. On the 28th day the various tests were conducted on the various samples.

Plate 8: Specimens in water tank

Plate 9: Specimens removed from tank after wet curing

3.3.10: Testing of specimens

3.3.10.1: Compressive Strength Test

The brick specimens were tested for both dry and wet compressive strength. The compressive strength tests were guided by ASTM C39 (1990). On the 28th day of curing specimens the samples were tested for both wet and dry compressive test. Three samples were selected from each group and were weighed. After weighing the samples their average masses were recorded. Their dimensions were also taken. The specimen were placed with flat faces horizontal, and mortar filled face facing upwards and carefully centered between plates of the compressive testing machine (Plate 10). The machine was put on and load was applied axially at a uniform rate till failure occurred. The maximum load and the corresponding strengths were recorded. This action was repeated for all the samples.

Plate 10: The compressive machine

3.3.10.2 Split Tensile Strength

This experiment was conducted to determine the shear resistance of each of the bricks. Three samples were randomly selected from each group. The specimens were tested after 28 days of air-dry curing. The samples were then weighed individually on the weighing balance and their dimensions were also taken and recorded. The two pieces of iron metals to split the bricks were arranged in the compressive crushing machine. The first piece of the iron metal was placed in the machine with the cutter facing up. Each sample was placed on the cutter and the second iron piece was placed on top of the brick with the cutter facing down. With an initial hand support of the apparatus in the compressive machine, the machine was put on and the specimens were pressed to cut. The load was applied continuously and without shock until the failure of the specimen. The maximum load used to split the specimen and the corresponding split strength were recorded (Details of the recorded values are in Appendix 3).

Plate 11: The splited brick

3.3.10.3 Water absorption test

Three samples were selected from each of the 10 groups of bricks and were dried in a ventilated oven at a temperature between 105 ^{0}C to 115 ^{0}C for 24 hours till they attain substantially constant mass (IS: 349 Part 2-1992). Before loading the specimens into the oven, the oven was put on for about 10 minutes for a uniform temperature within. The samples were arranged about 25mm apart in the oven. The samples were removed after 24 hours from the oven. Afterwards, they were allowed to cool in the open air for two hours. The samples were then weighed and dry weights (M1) were recorded. After the recordings they were fully immersed in water at room temperature for 24 hours. The samples were then removed and the water on them was wiped off with a cloth. Within three minutes of wiping off the bricks, they were weighed again on the weighing balance and their wet weights (M2) were also recorded.

Water absorption percentage by mass after 24 hours immersion in room temperature water is given by the following formula:

Water absorption = [(M2-M1) / M1] X 100

3.3.10.4 Abrasion Resistance

The abrasion resistance test was carried out to find out the specimens ability to resist wear. This was done with guidelines from ASTM C704-07 (2009). Three samples were selected from each of the 10 groups for the experiment. All the samples were first labeled and their initial weights were taken on the weighing balance. Iron brush was then used to brush the longitudinal section of each sample for 60 seconds to determine the rate of wearing.

A constant pressure was applied to the iron brush as it moves forwards and backwards along the longitudinal face of the brick for 60 seconds. One forward and backwards movement was counted as one and was done in a second for sixty times. So in all approximately one minute was spent on each sample. After brushing each sample they were weighed again and their final weights were recorded as well. The final weights were taken from the initial weights and the differences which represent the rate of abrasion were also recorded. The area of abrasion were also measured and recorded as well. The brush area was 35mm X 140mm. The abrasion resistance was calculated by dividing the abraded area by the abraded mass and the results recorded.

3.3.11 Data analysis

The values recorded from the tests, as exhibited in Appendices were analyzed using the Statistical Product and Service Solutions (version 21). Differences in the mechanical and engineering properties of the bricks and their aggregates were statistically tested in pairs of specimens. Also differences in pairs of multiples of specimens were analyzed using ANOVA. For example, differences in the split tensile strength of the controlled and experimental specimens as well as the differences in any three or more sets of specimens were tested using ANOVA. The analyses were summarized and presented in tables and charts.

CHAPTER FOUR

ANALYSIS OF RESULT

4.1 Introduction

Test result conducted on sandcrete bricks are analyzed and presented in this chapter. The analysis adopted for the study mainly involved the Two-way Analysis of Variance (ANOVA) to determine whether PKS size and prcentage replacement for sand had significant change on the mechanical and durability properties of sandcrete bricks.

Summary of experimental results are in tables and graphical presentation close to the text. Raw data are in Appendices for cross referencing.

4.2 Validity of Test Analysis of Study Result

To test the validity of the analysis, the Levene's test of equality of error variances was adopted and presented in Table 4.1. It is noted that test of equality of error variances for the properties investigated at the 5% level of significance except for wet compressive strength ($\alpha > 0.05$) and split tensile ($\alpha > 0.05$) strength were significant. This implies that the variations in the test result were equal and hence can be analyzed by Two-way ANOVA. Other assumptions such as numeric data, normal distribution of population and independent random sampling were all satisfied.

Table 4.1 Levene's Test of Equality of Error Variances

Dependent Variable	F	df1	df2	Sig.
Wet Compressive Strength	1.813	G	20	0.128
Dry Compressive Strength	4.345	G	20	0.003
Split Tensile Strength	1.894	G	20	0.112
Water Absorption	3.841	G	20	0.006
Abrasion Resistance	5.909	G	20	0.000

4.3 Mechanical Properties of Brick Specimen

Two mechanical properties of the specimens cast were tested including the compressive strength and the split tensile strength. However, the compressive strength tested comprised both the wet and dry compressive strength of the specimens. Explanation has been given to the result and analyzed using mainly Two-way ANOVA analysis.

Dry and wet compressive strengths were studied and the result is detailed in Table 4.2. Generally, at a constant PKS granular size compressive strength decreases with increase in PKS granular content for both wet and dry states. It was noted that for all specimens, the dry compressive strength were less than their corresponding wet compressive strengths.

Table 4.2 The compressive wet and dry strength of specimen

Variable	Compressive Strength (MPa)	
	Dry	Wet
A	28.29	30.1
B1.18/10	13.17	13.63
B1.18/20	6.17	8.99
B1.18/30	4.02	6.57
B2.36/10	20.43	27.84
B2.36/20	18.16	14.93
B2.36/30	16.19	14.83
B4.75/10	27.08	39.77
B4.75/20	25.66	33.47
B4.75/30	19.5	21.61

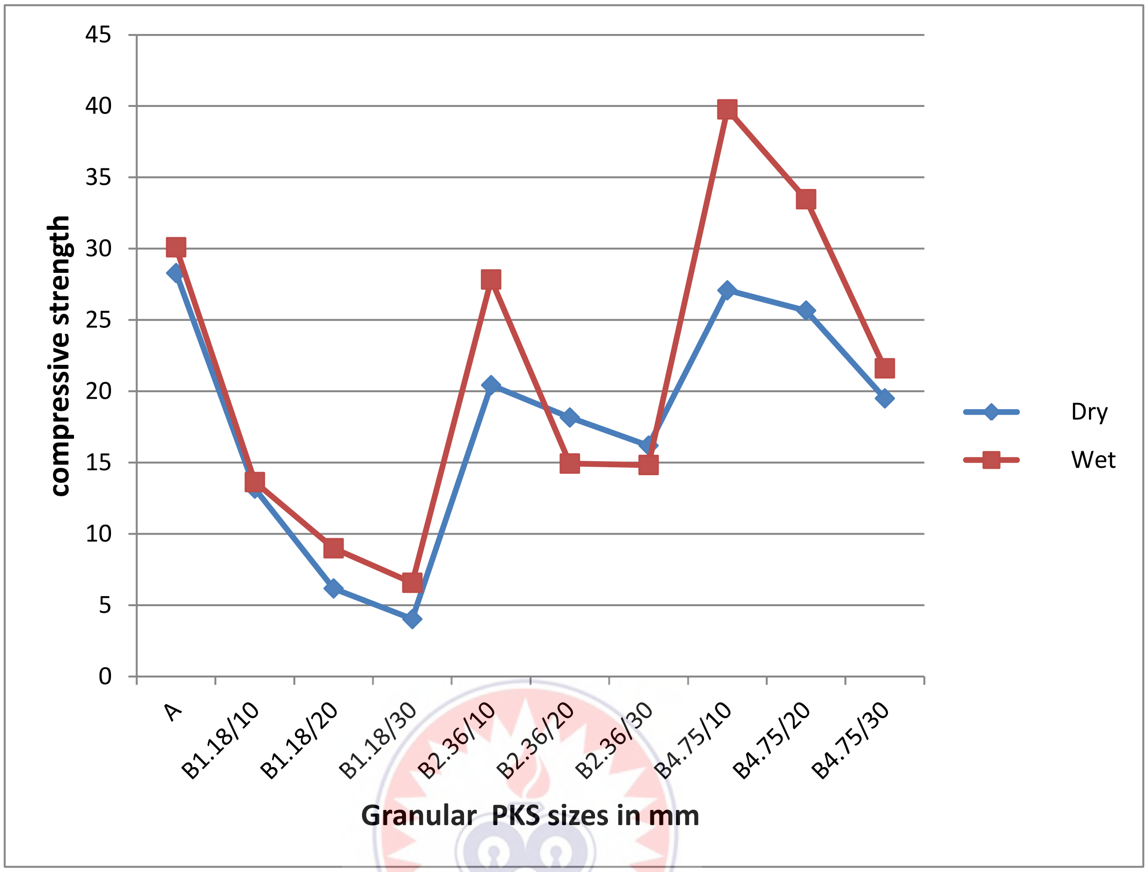

Figure 4.1: Dry Compressive Strength versus Wet Compressive strength

Key: *A* denote specimens with no PKS granular content whereas Bi/j denotes specimens with *imm* size of granular PKS and *j%* of granular PKS.

4.3.1 Wet Compressive strength test result

Table 4.3 presents the average result of the wet compressive strength of sandcrete brick specimen incorporating PKS sizes at different percentage replacement for sand. The result indicate that the addition of PKS to replace sand content generally reduced the wet compressive strength of brick specimen with the exception of 4.75mm size of PKS with 10% and 20% replacement compared to the control. Table 4.3 again indicates that, the wet compressive strength of bricks increased as the PKS size increased but decreased as the PKS sizes decreased and percentage of replacement increased. The reason can be that, bigger size of PKS had higher impact strength and also bond well with the sand particles yielding better compressive strength of the brick specimens. On the other hand, The reason is likely to be that the smaller particle sizes of PKS led to lower workability due to increase in surface area and hence greater friction.

Table 4.3 Wet Compressive Strength of Brick Specimen

Size of PKS	Percentage Replacement of PKS	Dimension (mm)	Average Weight (g)	Load (kN)	Mean Strength ± SD (MPa)
	0%	215x102.5x65	3182	663.3	30.10±2.252
1.18mm	10%	215x102.5x65	2820	300.3	13.63±1.290
	20%	215x102.5x65	2617	198.2	8.99±1.288
	30%	215x102.5x65	2411	144.8	6.57±1.732
2.36mm	10%	215x102.5x65	2965	480.2	27.84±0.726
	20%	215x102.5x65	2583	329.1	14.93±2.215
	30%	215x102.5x65	2595	326.8	14.83±1.601
4.75mm	10%	215x102.5x65	3194	876.5	39.77±0.683
	20%	215x102.5x65	3185	651.9	33.47±1.056
	30%	215x102.5x65	2882	476.2	21.61±1.045

Table 4.4 shows a Two-way ANOVA computed at the 5% level of significance of the wet compressive strength of sandcrete brick specimens incorporating PKS. The coefficient of multiple determination, R^2 shows about 98.7% (adjusted R^2 =0.981) variations in the wet compressive strength of sandcrete brick specimens can be explained by the size of PKS and their percentage replacement for sand. It can also be noted that, the particle size of PKS and the percentage replaced for sand resulted in a significant difference in the wet compressive strength of brick specimen ($F = 491.435$, $p < 0.001$ and $F = 168.979$, $p < 0.001$ respectively). This means that, depending on the size of PKS used to replace sand and the amount incorporated will decrease or increase the wet compressive significantly from when no PKS is added.

Table 4.4 Two-way ANOVA of Wet Compressive Strength of Brick Specimen

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	3357.407[a]	9	373.045	169.074	0.000
Intercept	13177.780	1	13177.780	5.973E3	0.000
PKS Size	2168.603	2	1084.301	491.435	0.000
% PKS Replacement	745.671	2	372.836	168.979	0.000
PKS Size*% PKS Replacement	177.654	4	44.414	20.129	0.000
Error	44.128	20	2.206		
Total	16853.801.	30			
Corrected Model	3401.535	29			

$R^2 = 0.987$ (Adjusted $R^2 = 0.981$);

4.3.2 Dry compressive strength test result

Table 4.5 shows the dry compressive strength of sandcrete brick specimens which had the control specimen achieving the highest compressive strength (28.29±0.218MPa). It can be noted that, the dry compressive strength of sandcrete brick specimens increased as the size of PKS replaced for sand increased. On the other hand, the dry compressive strength of brick specimens decreased as the percentage of PKS replaced for sand content increased. As explained earlier, bigger PKS sizes produced better bonding with sand than that of smaller sizes because the smaller sizes had lower workability due to increase in surface area and hence greater friction.

Table 4.5 Dry Compressive Strength of Brick Specimen

Size of PKS	Percentage Replacement of PKS	Dimension (mm)	Average Weight (g)	Load (kN)	Mean Strength ± SD (MPa)
	0%	215x102.5x65	3085	623.5	28.29±0.218
1.18mm	10%	215x102.5x65	2696	290.3	13.17±0.399
	20%	215x102.5x65	2349	135.9	6.17±0.381
	30%	215x102.5x65	2187	88.7	4.02±0.648
2.36mm	10%	215x102.5x65	2724	450.3	20.43±0.687
	20%	215x102.5x65	2793	400.2	18.16±1.115
	30%	215x102.5x65	2556	356.7	16.19±0.315
4.75mm	10%	215x102.5x65	3004	596.9	27.08±0.667
	20%	215x102.5x65	3013	565.6	25.66±0.979
	30%	215x102.5x65	2739	429.7	19.50±2.014

Table 4.6 presents a Two-way ANOVA of the dry compressive strength of sandcrete brick specimens which explains significant difference in the means caused by

PKS size and their percentage replacement for sand content in the bricks. The coefficient of multiple determination, R^2 indicate the size of PKS and the percentage replaced for sand explains about 99% (Adjusted R^2=0.9888) of the variations in the dry compressive strength of brick specimen. It is noted that PKS size and their percentage replacement for sand caused significance difference in the dry compressive strength of the brick specimens ($F = 762.680$, $p < 0.001$ and $F = 136.774$, $p < 0.001$ respectively).

Table 4.6 Two-way ANOVA of Dry Compressive Strength of Brick Specimen

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1851.456^a	9	205.717	255.663	0.000
Intercept	9726.314	1	9726.314	1.209E4	0.000
PKS Size	1227.371	2	613.686	762.680	0.000
% PKS Replacement	220.109	2	110.054	136.774	0.000
PKS Size*% PKS Replacement	41.939	4	10.485	13.030	0.000
Error	16.093	20	0.805		
Total	11445.869	30			
Corrected Model	1867.549	29			

$R^2 = 0.991$ (Adjusted $R^2 = 0.988$)

4.3.3 Split tensile strength test result

Split tensile strength of sandcrete bricks were tested and the result presented in Table 4.7 which follows the trend of the compressive strength. Thus, the split tensile strength increased with an increase in PKS size whereas it decreased when the percentage of PKS was increased in the mixture. It was observed that specimen with PKS size 2.36mm with 10% replacement, PKS size of 4.75mm with 10% and 20% replacement had higher split tensile strength than the control specimen.

Table 4.7 Split Tensile Strength of Brick Specimen

Size of PKS	Percentage Replacement of PKS	Dimension (mm)	Average Weight (g)	Load (kN)	Mean Strength ± SD (MPa)
Control	0%	215x102.5x65	3259	23.9	0.99±0.193
1.18mm	10%	215x102.5x65	2825	15.3	0.63±0.200
	20%	215x102.5x65	2444	7.9	0.32±0.140
	30%	215x102.5x65	2455	6.7	0.28±0.072
2.36mm	10%	215x102.5x65	2913	28.2	1.16±0.201
	20%	215x102.5x65	2560	15.9	0.66±0.262
	30%	215x102.5x65	2543	11.3	0.47±0.040
4.75mm	10%	215x102.5x65	3179	33.5	1.39±0.325
	20%	215x102.5x65	3049	26.8	1.11±0.320
	30%	215x102.5x65	2831	16.4	0.68±0.112

Table 4.8 presents the ANOVA statistical analysis of sandcrete bricks split tensile strength at the 5% level of significance. As indicated in Table 4.8, the size of PKS and the percentage replacement for sand had significant impact on the split tensile strength ($F=23.877$, $p<0.001$ and $F=19.97$, $p<0.001$ respectively). This means that, when the PKS size was increased and used to replace sand for brick making, the split tensile strength significantly increased. On the other hand, as the percentage of PKS replacement for sand increased the split tensile strength of sandcrete bricks significantly decreased. Moreover, the coefficient of multiple determination, R^2 indicate that the size of the PKS and the percentage replacement can explains about 83% (Adjusted $R^2=0.751$) of the variation in split tensile strength of brick specimens.

Table 4.8 Two-way ANOVA of Split Tensile Strength of Brick Specimen

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3.806^a	9	0.423	10.739	0.000
Intercept	16.836	1	16.836	427.515	0.000
PKS Size	1.881	2	0.940	23.877	0.000
% PKS Replacement	1.573	2	0.786	19.970	0.000
PKS Size*% PKS Replacement	0.189	4	0.047	1.200	0.341
Error	0.788	20	0.039		
Total	22.304	30			
Corrected Model	4.594	29			

$R^2 = 0.829$ (Adjusted $R^2 = 0.751$)

4.4 Durability Properties of Brick Specimen

The durability properties conducted for this study included the water absorption and abrasion resistance of the brick specimens of which their results are analyzed.

4.4.1 Water absorption of brick specimen

Table 4.9 records the water absorption observed for the brick specimens which indicate that water absorption rate increased with an increase in percentage replacement of PKS for PKS size of 2.36mm and 4.75mm. Meanwhile, for 1.18mm PKS size, the water absorption rate increased from 10% to 20% PKS replacement and decreased for 30% PKS replacement. Maximum water absorption rate was however achieved for sandcrete brick specimens with 2.36mm PKS size and 30% replacement. This implies that, water absorption increased with an increase in the percentage of PKS replacement for sand specimen. This can be attributed to the fact that, more PKS in a mixture requires more water to saturate the surface of PKS. Consequently, more water is absorbed by specimen with higher percentage of PKS replacement in order to keep the specimen at the saturated surface. It is again observed that specimen with 1.18mm PKS size and 10% replacement, 4.75mm with 10% and 20% replacement had lower absorption rate than that of the control specimen.

Table 4.9 Water Absorption Rate of Brick Specimens

Size of PKS	Percentage Replacement of PKS	Dimension (mm)	Average Dry Weight (g)	Average Wet Weight (g)	Difference in Weight (g)	Percentage Rate of Absorption (%)
	0%	215x102.5x65	2969	3127	158	4.28
1.18mm	10%	215x102.5x65	2893	2960	67	2.32
	20%	215x102.5x65	2334	2467	133	5.74
	30%	215x102.5x65	2295	2403	108	4.75
2.36mm	10%	215x102.5x65	2781	2901	120	4.30
	20%	215x102.5x65	2442	2642	200	8.16
	30%	215x102.5x65	2324	2525	201	8.67

4.75mm	10%	215x102.5x65	3061	3157	96	3.10
	20%	215x102.5x65	2848	2941	93	3.33
	30%	215x102.5x65	2756	2927	171	6.28

Table 4.10 presents the Two-way ANOVA of the water absorption rate of sandcrete bricks tested which explains that the variations in the water absorption rate can be explained by the PKS size and percentage of PKS replaced for sand content. The coefficient of multiple determination, R^2 suggest that the size of PKS size and the percentage replaced for sand can explain about 61% (Adjusted $R^2 = 0.437$) of the variations in the water absorption rate of brick specimens. It is observed that PKS size and their percentage replacement significantly affect the water absorption rate of brick specimens. Impliedly, the water absorption rate significantly increased when the size of PKS and the percentage of PKS were increased ($F=6.09$, $P<0.01$ and $F=7.047$, $P<0.01$ respectively).

Table 4.10 Two-way ANOVA of Water Absorption Rate of Brick Specimen

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	120.791[a]	9	13.421	3.497	0.009
Intercept	666.060	1	666.060	173.548	0.000
PKS Size	46.747	2	23.374	6.090	0.009
% PKS Replacement	54.095	2	27.048	7.047	0.005
PKS Size*% PKS Replacement	17.749	4	4.437	1.156	0.360
Error	76.758	20	3.838		
Total	975.505	30			
Corrected Model	197.549	29			

$R^2 = 0.611$ (Adjusted $R^2 = 0.437$)

4.5.2 Abrasion resistance of brick specimen

The average abrasion resistances of brick specimens are presented in Table 4.11 which show a general decrease in the abrasion resistance as the percentage of PKS is increased. However, the abrasion resistance for 20% PKS replacement of size 4.75mm was found to be higher than that of 10% PKS replacement for sand. At constant percentage replacement of sand by PKS except for 10%, the abrasion resistant of sandcrete brick specimen increased with an increase in PKS size. It is again noticed from Table 4.11 that except for 10% and 20% replacement for PKS size of 4.75mm, the abrasion resistance were lower than that of the control specimen which had 18.81cm^2/g.

Table 4.11 Abrasion Resistance of Brick Specimens

Size of PKS	**Percentage Replacement of PKS**	**Dimension (mm)**	**Mass Before Abrasion (g)**	**Mass After Abrasion (g)**	**Difference in Mass (g)**	**Abraded Area (cm^2)**	**Abrasion Resistance (cm^2/g)**
	0%	215x102.5x65	3116	3112	4	75.25	18.81
1.18mm	10%	215x102.5x65	2632	2624	5.33	75.25	14.11
	20%	215x102.5x65	2433	2401	17.22	75.25	4.37
	30%	215x102.5x65	2374	2334	25.77	75.25	2.92
2.36mm	10%	215x102.5x65	2711	2704	6.09	75.25	12.36
	20%	215x102.5x65	2625	2615	9.39	75.25	8.01
	30%	215x102.5x65	2448	2431	25	75.25	4.63
4.75mm	10%	215x102.5x65	2978	2975	2.5	75.25	30.10
	20%	215x102.5x65	3101	3098	2.40	75.25	31.35
	30%	215x102.5x65	2711	2702	8.99	75.25	8.37

Results obtained by a Two-way ANOVA test is presented in Table 4.12 indicates significant difference in the abrasion resistance of test specimen. The coefficient of multiple determination, R^2 indicate PKS size and their percentage replacement explains about 76% (Adjusted R^2 =0.655) of the variations in the abrasion resistance of the sandcrete bricks. Thus, the PKS size and their percentage replacement for sand content in the manufacture of sandcrete bricks have significant effect on the abrasion resistance of the specimens. Impliedly, an increase in the PKS size in sandcrete bricks manufacture significantly increased ($F = 16.257$, $p < 0.001$) the abrasion resistance of the specimen. On the other hand, when the percentage of sand replacement of PKS is increased, the abrasion resistance of the specimen significantly decreased ($F = 9.641$, $p < 0.01$).

Table 4.12 Two-way ANOVA of Abrasion Resistance of Brick Specimen

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2863.871[a]	9	318.208	7.106	0.000
Intercept	5325.788	1	5325.788	118.929	0.000
PKS Size	1455.984	2	727.992	16.257	0.000
% PKS Replacement	863.509	2	431.755	9.641	0.001
PKS Size*% PKS Replacement	450.580	4	112.645	2.515	0.074
Error	895.621	20	44.781		
Total	9231.313	30			
Corrected Model	3759.492	29			

$R^2 = 0.762$ (Adjusted $R^2 = 0.655$)

CHAPTER FIVE

DISCUSSION OF RESULTS

5.1 Mechanical Properties of Brick Specimen

5.1.1 Compressive strength test result

5.1.1.1 Wet Compressive strength of brick specimen

The experimental study conducted indicates that the compressive strength of sandcrete bricks with PKS replacement for sand had lower strength than control specimen except 4.75mm size of 10% and 20% replacement. In agreement with the findings of Ohisola and Babafemi (2013), the wet compressive strength of brick specimen increased as the PKS size increased. This was attributed to the fact that, bigger PKS size had higher impact strength because the particles had a lower surface area hence lower friction resulting to higher compressive strength. The study result again supports literature (Olutoge, 2010; Dadzie & Yankah, 2015; Ohetaiwo & Owolabi, 2015) that an increase in the percentage replacement of sand with PKS resulted to a decrease in the compressive strength.

Moreover, the study result was statistically proven worthy as in the significant change in compressive strength when the sand content is replaced by PKS size and percentage of replacement ($F=491.435$, $P<0.001$ and $F=168.979$, $P<0.001$ respectively with $R^2=98.7\%$). Impliedly, the compressive strength of sandcrete bricks will increase or decrease depending on the size of PKS replaced for sand or the volume of PKS used in the mixture.

5.1.1.2 Dry Compressive strength of brick specimen

Compared to the wet compressive strength, lower compressive strengths were achieved for the air dry curing. All compressive strengths for sandcrete bricks with PKS replacement were found to be lower than that of the control specimen (28.29=0.218Mpa). Confirming literature (Olusola & Babafemi, 2013) and the wet compressive strength increased with an increase in the PKS replaced for sand increased (Olutoge, 2010; Dadzie & Yankah, 2015; Olataiwo & Owolabi, 2015). Meanwhile, Two way analysis of variance supported the findings that PKS size and their percentage replacement for sand significantly affect the dry compressive strength (F=762.680, P<0.001 and F=136.774, P<0.001 respectively with R^2 99%).

5.1.2 Split tensile strength test result

Split tensile strength of sandcrete bricks were tested and the result presented which follows the trend of the compressive strength. Thus, the split tensile strength increased with an increase in PKS size whereas it decreased when the percentage of PKS was increased in the mixture. It was observed that specimen with PKS size 2.36mm with 10% replacement, PKS size of 4.75mm with 10% and 20% replacement had higher split tensile strength than the control specimen.

Furthermore, the study presented the ANOVA statistical analysis of sandcrete bricks split tensile strength at the 5% level of significance. As indicated in Table 4.6, the size of PKS and the percentage replacement for sand had significant impact on the split tensile strength (F=23.877, p<0.001 and F=19.97, p<0.001 respectively). This means that, when the PKS size was increased and used to replace sand for brick making, the split tensile strength significantly increased. On the other hand, as the percentage of PKS replacement for sand increased the split tensile strength of sandcrete bricks significantly decreased. This result agrees with the findings of the research conducted by Olusola and Babefemi (2013). In their study they conducted an investigation into the effect of coarse aggregate size and replacement level of granite with palm kernel shell (PKS) on the compressive and tensile strengths of PKS concrete were investigated.

5.2 Durability Properties of Brick Specimen

5.2.1 Water absorption of brick specimen

It was observed that water absorption rate increased with an increase in percentage replacement of PKS for PKS size of 2.36mm and 4.75mm. Meanwhile, for 1.18mm PKS size, the water absorption rate increased from 10% to 20% PKS replacement and decreased for 30% PKS replacement. Maximum water absorption rate was however achieved for sandcrete brick specimens with 2.36mm PKS size and 30% replacement. This implies that, more water was absorbed by the amount of PKS in the specimen. It is again observed that specimen with 1.18mm PKS size and 10% replacement, 4.75mm with 10% and 20% replacement had lower absorption rate than that of the control specimen.

The study shows that the Two-way ANOVA of the water absorption rate of sandcrete bricks tested which explains that the variations in the water absorption rate can be explained by the PKS size and percentage of PKS replaced for sand content. The coefficient of multiple determination, R^2 suggest that the size of PKS size and the percentage replaced for sand can explain about 61% (Adjusted R^2 = 0.437) of the variations in the water absorption rate of brick specimens. It is observed that PKS size and their percentage replacement significantly affect the water absorption rate of brick specimens. Impliedly, the water absorption rate significantly increased when the percentage of PKS were increased. This contradicts with the study conducted by Muntohar and Rahman (2014), they made an experimental study on the development of the shellcrete masonry block that made use of palm kernel shell (PKS). The masonry block was called shellcrete. The study focused on the physical, compressive and flexural strengths of shellcrete. The shellcrete was made by mixing the Portland cement (PC), sand, and oil palm kernel shell (PKS). A control specimen made of PC and sand mixture (sandcrete) was also prepared. The maximum strength obtained was 22MPa by mixing proportion of 1 PC:1 Sand:1 PKS, but the recommended mix proportion of the shellcrete for building materials was 1 PC:1 Sand:2 PKS as an optimum mix design for eco-friendly shellcrete. The best mix design was 1:1:2 (OPC: sand: PKS). The study revealed that the shellcrete was acceptable for lightweight materials and masonry block.

As part of Olutoge's (2010) study, he investigated the use of palm kernel shells (PKS) as replacement for fine and coarse aggregates in reinforced concrete slabs. Reinforced concrete slabs measuring 800 x 300 x 75mm were cast. PKS were used to replace both fine and coarse aggregates from 0% to 100% in steps of 25%. Flexural strengths were evaluated at 7, 14 and 28 days and compressive strengths were evaluated at 28 days as shown in Table 2.1. Olutoge (2010) found that increase in percentage of palm kernel shells in concrete slabs led to a corresponding reduction in both flexural and compressive strength values. The study found that at a low replacement value of 25% PKS can produce lightweight reinforced concrete slabs which could be used where low stress is required at reduced cost. A weight reduction 17.9% was achieved for PKS replacement slabs.

Dadzie and Yankah (2015) explored and compared the properties of masonry blocks produced with palm kernel shell (PKS) as partial replacement to the traditional sandcrete blocks in an attempt to establish the percentage replacement of PKS that yields properties and characteristics that meets acceptable standards. They batched their samples by a mix proportion of (1:6). The PKS replacement varies from 0%, 10%, 20%, 30%, 40% and 50% with water cement ratio of 0.5. Total of 24 blocks were moulded, cured for 28days, subjected to various tests including water absorption, weight, density, and compressive strength. With regard to strength test, they found that the compressive strength of the PKS blocks exceeds the minimum requirement of 2.8N/mm2 when the PKS replacement do not exceeds 40%.

Olutaiwo and Owolabi (2015) evaluated the effect of partial replacement of coarse aggregate (4-8mm crushed stone) with graded palm kernel shell in asphaltic wearing course. They evaluated the volumetric and physical properties of the asphalt mixtures in order to determine the performance characteristics of PKS in the mass production of wearing course asphalt concrete for medium traffic road. Percentages of PKS used were 0%, 30%, 50%, 70% and 100%. Specifically, 15 samples for control mix and 60 samples for the PKS proportions of compacted asphalt mixtures were prepared by using Marshall mixing procedure. The samples were prepared by varying bitumen contents from 5.0% to 7.0% in an increment of 0.5% and tested using the Marshall method. The results indicated that the mixture at 30% PKS meets the criteria provided in the Asphalt Institute Standard Specification. It was observed that for medium trafficked roads, graded palm kernel shells between 10%-30% by weight of coarse aggregate (4-

8mm crushed stone) can be used for the replacement while even 100% replacement is possible for lightly trafficked rural roads.

In the empirical studies it was noted that in each of the cases where coarse aggregates were replaced by PKS, the strength of the blocks reduced in comparison with regular concrete (Olutoge, 2010), sandcrete (Dadzie & Yankah, 2015), and even asphaltic mixtures (Olutaiwo & Owolabi, 2015). In all cases, the strength of the mixtures reduced further, as the percentage of PKS in the mixtures increased. The studies indicated that the optimum replacement level of coarse aggregate is 25% (Olutoge, 2010) but should not exceed 40% (Dadzie & Yankah, 2015).

This comes to an agreement with ASTM-C140, (2000). They asserted that water can enter the pores in the cement paste and even in the aggregate, and this weakens the slabs of masonry block when prolonged. One of the most important properties of a good quality masonry block is, therefore, low permeability (ASTM-C140, 2000). Low permeability means that the masonry unit can resist ingress of water and is not as susceptible to freezing and thawing (ASTM-C140, 2000). Low resistance to water permeation is important for reducing cracks, foliation, and structural deformation. Some studies have investigated the water absorption properties of blocks made with PKS.

In Olanipekun et al.'s (2006) study, it was reported that the percentage of water absorption increases with increase in the percentage replacement level of coarse aggregate with PKS. For mix ratio 1:1:2, the value range from 0.41% to 5.88% for PKS concrete (10% to 100% replacement levels). Teo et al. (2007) also found that the water absorption of PKS concrete under air drying curing and full water curing were 11.23% and 10.64% respectively.

Ohemeng et al. (2015) conducted a study which partly analysed water absorption of blocks made with PKS. They found that the water absorption increases as the percentage of the palm kernel aggregate rises. The water absorption moved from 1.46% to 1.77%, indicating a rise of about 21% when 60% of the sand was substituted with PKS aggregates. It can be noticed that the water absorption values found in this study are within that of normal weight concrete. They found that a linear relationship between palm kernel content and percentage increase in water absorption. The R^2 of 0.9962 indicated that 99.62% of the variation in water absorption can be explained by palm kernel shell content.

Ekong (2015) also carried out water absorption tests on PKS particle sizes graded into 1mm, 2mm, 3mm and 4mm. Water absorption tests were carried out for each grade of PKS. Water absorption test was performed by a 24 hour immersion in cold water. A known mass of 20g of each particle grade of PKS was preconditioned by drying in a test kiln at 110ºC. This was to ensure total water loss in the samples. After they were allowed to cool at room temperature, each particle grade was weighed and the dry (initial) mass was recorded. Each of the preconditioned particle grades was immersed in cold water and allowed for 24 hours in room temperature. Thereafter, the samples were collected in a 75 micron mesh. This was in order to get rid of excess water. The residue was weighed and the new mass recorded against the initial mass. The percentage water absorption for each sample was then calculated using the formula: Mass of water absorbed x 100 /Initial mass of substance (PKS)

The study found that PKS does not absorb water above 45%. The 1mm grade which absorbs water above 45% is enhanced by its high fibre contents. Fibre was high in the grade because they could not pass through the mesh. The 2mm grade which had about the most ideal water absorption had just 10%, while 3mm and 4mm grades had 25% each. The water absorption tests showed low percentage absorbency. The high absorption rate obtained from 1mm grade of palm kernel shells is, perhaps, due to its fibre content since this was not present in other grades.

5.2.2 Abrasion resistance of brick specimen

The average abrasion resistance of brick specimens is presented in Table 4.11 which show a general decrease in the abrasion resistance as the percentage of PKS is increased. However, the abrasion resistance for 20% PKS replacement of size 4.75mm was found to be higher than that of 10% PKS replacement for sand. The reason could not be explained. At constant percentage replacement of sand by PKS except for 10%, the abrasion resistant of sandcrete brick specimen increased with an increase in PKS size. It is again noticed from Table 4.9 that except for 10% and 20% replacement for PKS size of 4.75mm, the abrasion resistance were lower than that of the control specimen which had 18.81cm^2/g.

Moreover, the results obtained by a Two-way ANOVA tests are presented in Table 4.10 indicate significance difference in the abrasion resistance of test specimen. The coefficient of multiple determination, R^2 indicate PKS size and their percentage replacement explains about 76% of the variations in the abrasion resistance of the sandcrete bricks. Thus, the PKS size and their percentage replacement for sand content in the manufacture of sandcrete bricks have significant effect on the abrasion resistance of the specimens. Impliedly, an increase in the PKS size in sandcrete bricks manufacture significantly increased ($F = 16.257$, $p < 0.001$) the abrasion resistance of the specimen.

On the other hand, when the percentage of sand replacement of PKS is increased, the abrasion resistance of the specimen significantly decreased ($F = 9.641$, $p < 0.01$).

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

The purpose of the study was to use granular palm kernel shells (PKS) of varying sizes to partially replace sand in sandcrete bricks. This chapter contains the summary of the main findings of the study, conclusions and recommendations for further study.

6.2 Summary

6.2.1 Compressive strength of brick specimen

1. The study result indicates that the addition of PKS to replace sand content generally reduced the compressive strength of brick specimen.
2. The wet compressive strength was generally higher than the dry compressive strength.
3. Compressive strength increased significantly ($F=491$; $P<0.001$) with an increase in the PKS size to replace sand content.
4. The compressive strength of brick specimens decreased significantly ($F = 491.435$, $p < 0.001$ and $F = 168.979$, $p < 0.001$ respectively).
5. A higher percentage of PKS in the mortar resulted to a weaker bonding as it requires enough sand particles to produce the needed strength.
6. The particle size of PKS and the percentage replaced for sand resulted in a significant difference in the wet compressive strength of brick specimen ($F = 491.435$, $p < 0.001$ and $F = 168.979$, $p < 0.001$ respectively).

7. The study indicates that the dry compressive strength of sandcrete brick specimens which has the control specimen achieving the highest compressive strength (28.29±0.218MPa).
8. The dry compressive strength of sandcrete brick specimens increased as the size of PKS replaced for sand increased. On the other hand, the dry compressive strength of brick specimens decreased as the percentage of PKS replace for sand content increased.
9. Bigger PKS produced better bonding with sand than that of smaller size which has lesser impact value therefore reducing the entire strength of the mortar matrix.

6.2.2 Split tensile strength of brick specimens

1. The study shows that the split tensile strength increased with an increase in PKS size whereas it decreased when the percentage of PKS was increased in the mixture.
2. It was observed that specimen with PKS size 2.36mm with 10% replacement, PKS size of 4.75mm with 10% and 20% replacement had higher split tensile strength than the control specimen.
3. The size of PKS and the percentage replacement for sand had significant impact on the split tensile strength ($F=23.877$, $p<0.001$ and $F=19.97$, $p<0.001$ respectively). This means that, when the PKS size was increased and used to replace sand for brick making, the split tensile strength significantly increased.
4. On the other hand, as the percentage of PKS replacement for sand increased the split tensile strength of sandcrete bricks significantly decreased.

6.2.3 Water absorption of brick specimen

1. The study indicated that water absorption rate increased with an increase in percentage replacement of PKS for PKS size of 2.36mm and 4.75mm.
2. Meanwhile, for 1.18mm PKS size, the water absorption rate increased from 10% to 20% PKS replacement and decreased for 30% PKS replacement.
3. Maximum water absorption rate was however achieved for sandcrete brick specimens with 2.36mm PKS size and 30% replacement. This implies that, more water was absorbed by the amount of PKS in the specimen.
4. It is again observed that specimen with 1.18mm PKS size and 10% replacement, 4.75mm with 10% and 20% replacement had lower absorption rate than that of the control specimen. The reason could not be explained for this observation.

6.2.4 Abrasion resistance of brick specimen

1. The research report show a general decrease in the abrasion resistance as the percentage of PKS is increased.
2. However, the abrasion resistance for 20% PKS replacement of size 4.75mm was found to be higher than that of 10% PKS replacement for sand.
3. At constant percentage replacement of sand by PKS except for 10%, the abrasion resistant of sandcrete brick specimen increased with an increase in PKS size.
4. It is again noticed from Table 4.11 that except for 10% and 20% replacement for PKS size of 4.75mm, the abrasion resistance were lower than that of the control specimen which had 18.81cm^2/g.

5. The PKS size and their percentage replacement for sand content in the manufacture of sandcrete bricks have significant effect on the abrasion resistance of the specimens.
6. Impliedly, an increase in the PKS size in sandcrete bricks manufacture significantly increased ($F = 16.257$, $p < 0.001$) the abrasion resistance of the specimen. On the other hand, when the percentage of sand replacement of PKS is increased, the abrasion resistance of the specimen significantly decreased ($F = 9.641$, $p < 0.01$).

6.3 Conclusions

1. The study concluded that the addition of PKS to replace sand content generally reduced the compressive strength of brick specimen.
2. Moreover, the compressive strength of brick increased as the PKS size increased but decreased as the percentage of replacement increased.
3. Also, the split tensile strength increased with an increase in PKS size whereas it decreased when the percentage of PKS was increased in the mixture.
4. Meanwhile, for 1.18mm PKS size, the water absorption rate increased from 10% to 20% PKS replacement and decreased for 30% PKS replacement.
5. However, the abrasion resistance for 20% PKS replacement of size 4.75mm was found to be higher than that of 10% PKS replacement for sand.

6.4 Recommendations

According to the major findings and conclusions of the study, the researcher recommends that;

1. The Government of Ghana should empower Civil engineers and other contractors to use palm kernel shell (PKS) aggregate as a partial replacement in convectional sandcrete in the locality where it is in abundance to enhance environmental cleanliness.
2. A study of the shrinkage characteristics of PKS sandcrete bricks should be conducted.
3. A long term durability study of PKS sandcrete bricks should be investigated.
4. The study of the permeability properties of PKS sandcrete bricks should be investigated.

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APPENDICES

APPENDIX 1: COMPRESSIVE STRENGTH (DRY) TEST RESULTS

Percentage	Size	Dimension	Mass(g)	Average Mass	Load (KN)	Strength (N/mm2	Average Strength
0%	1	215x102.5x65	2971		626.7	28.44	
	2	215x102.5x65	3113	3084.67	618	28.04	28.29
	3	215x102.5x65	3170		625.7	28.39	
	1.18mm						
10%	1	215x102.5x65	2728		300.4	13.63	
	2	215x102.5x65	2718	2695.67	284	12.89	13.17
	3	215x102.5x65	2641		286.4	13	
20%	1	215x102.5x65	2437		139.8	6.34	
	2	215x102.5x65	2214	2348.67	141.7	6.43	6.17
	3	215x102.5x65	2395		126.3	5.73	
30%	1	215x102.5x65	1997		76.7	3.48	
	2	215x102.5x65	2220	2187.33	84.9	3.85	4.02
	3	215x102.5x65	2345		104.5	4.74	
	2.36mm						
10%	1	215x102.5x65	2705		381.4	17.31	
	2	215x102.5x65	2819	2793	391.4	17.76	18.16
	3	215x102.5x65	2855		427.9	19.42	
20%	1	215x102.5x65	2826		466.6	21.17	
	2	215x102.5x65	2641	2724	447.7	20.32	20.43
	3	215x102.5x65	2706		436.6	19.81	
30%	1	215x102.5x65	2583		352.4	15.99	
	2	215x102.5x65	2467	2556	353.1	16.02	16.19
	3	215x102.5x65	2617		364.7	16.55	

	4.75mm						
10%	1	215x102.5x65	3041		595.5	27.02	
	2	215x102.5x65	3065	3004	612.19	27.78	27.08
	3	215x102.5x65	2906		582.92	26.45	
20%	1	215x102.5x65	3082		557.04	25.28	
	2	215x102.5x65	3020	3013	590.18	26.78	25.66
	3	215x102.5x65	2936		549.54	24.94	
30%	1	215x102.5x65	2612		401.03	18.2	
	2	215x102.5x65	2897	2739	480.85	21.82	19.5
	3	215x102.5x65	2707		407.32	18.48	

APPENDIX 2: COMPRESSIVE TEST (WET) RESULTS

	0%	Dimension	Mass(g)	Average Mass	Load (KN)	Strength (N/mm2	Average Strength
	1	215x102.5x65	3257	3182	690.6	31.34	
	2	215x102.5x65	3190		693.4	31.46	
	3	215x102.5x65	3099		606	27.5	30.1
1.18mm							
10%	1	215x102.5x65	2791	2820	316.9	14.38	
	2	215x102.5x65	2688		267.5	12.14	
	3	215x102.5x65	2980		316.6	14.37	13.63
20%	1	215x102.5x65	2398	2411	123.4	5.6	
	2	215x102.5x65	2474		188.8	8.57	
	3	215x102.5x65	2361		122.1	5.54	6.57
30%	1	215x102.5x65	2634	2617	201.9	9.16	
	2	215x102.5x65	2662		224.5	10.19	
	3	215x102.5x65	2556		168.2	7.63	8.99
2.36mm							
10%	1	215x102.5x65	2926	2965	214.4	27.88	
	2	215x102.5x65	3094		629.1	28.55	
	3	215x102.5x65	2874		597.2	27.1	27.84
20%	1	215x102.5x65	2724	2583	354.6	16.09	
	2	215x102.5x65	2409		272.8	12.38	
	3	215x102.5x65	2615		359.9	16.33	14.93
30%	1	215x102.5x65	2520	2595	332.6	15.09	
	2	215x102.5x65	2402		289	13.12	
	3	215x102.5x65	2862		358.9	16.29	14.83
4.75mm							
10%	1	215x102.5x65	3139	3185	725.7	32.93	
	2	215x102.5x65	3299		764.4	34.69	
	3	215x102.5x65	3117		722.9	32.8	33.47
20%	1	215x102.5x65	2771	2882	465.5	21.12	
	2	215x102.5x65	2882		502.7	22.81	21.61

	3	215x102.5x65	2992		460.5	20.9	
30%	1	215x102.5x65	2987	3194	870	39.48	
	2	215x102.5x65	3254		865.7	39.28	
	3	215x102.5x65	3340		893.7	40.55	39.77

APPENDIX 3: SPLIT TENSILE STRENGTH RESULTS

Samples		Dimension	Mass (g)	Average Mass	Load	Strength (N/mm2)	Average Strength
0%	1	215x102.5x65	3248	3259	29.3	1.21	0.99
	2	215x102.5x65	3413		20.5	0.85	
	3	215x102.5x65	3117		22	0.91	
1.18mm							
10%	1	215x102.5x65	2773	2825	15.3	0.63	0.63
	2	215x102.5x65	2971		15.8	0.65	
	3	215x102.5x65	2730		14.7	0.61	
20%	1	215x102.5x65	2348	2455	5.3	0.22	0.28
	2	215x102.5x65	2317		6.2	0.26	
	3	215x102.5x65	2701		8.7	0.36	
30%	1	215x102.5x65	2478	2444	8.1	0.33	0.32
	2	215x102.5x65	2176		4.3	0.18	
	3	215x102.5x65	2679		11.2	0.46	
2.36mm							
10%	1	215x102.5x65	3045	2913	32.3	1.33	1.16
	2	215x102.5x65	2911		29.6	1.22	
	3	215x102.5x65	2784		22.7	0.94	
20%	1	215x102.5x65	2501	2543	10.4	0.43	0.47
	2	215x102.5x65	2527		11.2	0.46	
	3	215x102.5x65	2601		12.3	0.51	
30%	1	215x102.5x65	2674	2560	14.9	0.62	0.66
	2	215x102.5x65	2365		10.1	0.42	
	3	215x102.5x65	2640		22.8	0.94	
4.75mm							
10% PKS	1	215x102.5x65	2973	3179	25.6	1.06	1.39
	2	215x102.5x65	3448		41.3	1.71	
	3	215x102.5x65	3116		33.7	1.39	
20%	1	215x102.5x65	2952	3049.33	33.7	1.39	1.11
	2	215x102.5x65	3003		18.4	0.76	

PKS						
	3	215x102.5x65	3193		28.4	1.17	
30% PKS	1	215x102.5x65	2645	2830.67	14.1	0.58	0.68
	2	215x102.5x65	2774		19.3	0.8	
	3	215x102.5x65	3073		15.7	0.65	

APPENDIX 4: WATER ABSORPTION TEST RESULTS

Sample		Dimension	Dry weight (g)	Average Dry weight (g)	Wet Weight(g)	Average wet Weight(g)	Percentage rate of absorption (M2-M1/M1*100%)	Load (KN)	strength	average
0%										
	1	215X102.5x65	2969	2999	3118	3127	5.02	578.8	26.26	27.01
	2	215X102.5x65	3077		3184		3.48	640.7	29.07	
	3	215X102.5x65	2951		3079		4.34	566.3	25.7	
1.18mm										
10%	1	215X102.5x65	2841	2893.3	2923	2960	2.89	442.4	20.07	19.61
	2	215X102.5x65	2972		3035		2.12	417.5	18.94	
	3	215X102.5x65	2867		2923		1.95	436.8	19.82	
20%	1	215X102.5x65	2462	2334.3	2561	2467	4.02	143.9	6.53	6.48
	2	215X102.5x65	2299		2456		6.83	142.5	6.46	
	3	215X102.5x65	2242		2385		6.38	142	6.44	
30%	1	215X102.5x65	2341	2295.3	2401	2403	2.56	141.5	6.42	5.9
	2	215X102.5x65	2224		2429		9.22	124.3	5.64	
	3	215X102.5x65	2321		2378		2.46	124.1	5.63	
2.36mm										
10%	1	215X102.5x65	2695	2781.3	2820	2901	4.64	483.8	21.95	23.82
	2	215X102.5x65	2816		2940		4.4	542.8	24.63	
	3	215X102.5x65	2833		2942		3.85	548.1	24.87	

20%	1	215X102.5x65	2301	2324.3	2469	2525	7.3	181.9	8.25	8
	2	215X102.5x65	2276		2548		11.95	169.3	7.68	
	3	215X102.5x65	2396		2558		6.76	177.5	8.06	
30%	1	215X102.5x65	2454	2442.3	2708	2642	10.35	276.3	12.54	12.54
	2	215X102.5x65	2457		2599		5.78	294.6	13.37	
	3	215X102.5x65	2416		2618		8.36	258.1	11.71	
4.75mm										
10%	1	215X102.5x65	3050	3061.3	3159	3156.7	3.57	621.4	28.2	29.16
	2	215X102.5x65	2959		3023		2.16	661.5	30.02	
	3	215X102.5x65	3175		3288		3.56	645.1	29.27	
20%	1	215X102.5x65	2799	2848	2866	2940.7	2.39	636.9	28.9	28.74
	2	215X102.5x65	3081		3146		2.11	650.6	29.52	
	3	215X102.5x65	2664		2810		5.48	612.7	27.8	
30%	1	215X102.5x65	3009	2756.3	3147	2927	4.59	293.2	13.3	12.61
	2	215X102.5x65	2569		2768		7.75	277.4	12.59	
	3	215X102.5x65	2691		2866		6.5	263.4	11.95	

APPENDIX 5: ABRASION TEST RESULTS

Samples		Dimension	Initial weight	Weight after abrasion	Difference (g)	Area of abrasion
0%	1	215x102.5x65	3133	3129	**4**	45x215
	2	215x102.5x65	3110	3106	**4**	45x216
	3	215x102.5x65	3105	3101	**4**	45x217
1.88mm						
10%	1	215x102.5x65	2628	2622	**6**	40x215
	2	215x102.5x65	2576	2560	**16**	50x215
	3	215x102.5x65	2692	2689	**3**	45x215
20%	1	215x102.5x65	2576	2563	**13**	45x215
	2	215x102.5x65	2287	2216	**71**	50x215
	3	215x102.5x65	2436	2424	**12**	48x215
30%	1	215x102.5x65	2609	2595	**14**	45x215
	2	215x102.5x65	2141	2068	**73**	50x215
	3	215x102.5x65	2372	2340	**32**	48x215
2.36mm						
10%	1	215x102.5x65	2900	2896	**4**	42x215
	2	215x102.5x65	2533	2523	**10**	45x215
	3	215x102.5x65	2700	2693	**7**	45x215
20%	1	215x102.5x65	2599	2587	**12**	45x215
	2	215x102.5x65	2714	2706	**8**	45x215
	3	215x102.5x65	2562	2553	**9**	45x215
30%	1	215x102.5x65	2441	2426	**15**	45x215
	2	215x102.5x65	2428	2410	**18**	45x215
	3	215x102.5x65	2474	2458	**16**	46x215
4.75mm						
10%	1	215x102.5x65	2990	2988	**2**	45x215
	2	215x102.5x65	3038	3036	**2**	40x215
	3	215x102.5x65	2906	2901	**5**	40x215

20%	1	215x102.5x65	3269	3267	**2**	45x215
	2	215x102.5x65	3045	3041	**4**	45x216
	3	215x102.5x65	2988	2986	**2**	45x217
30%	1	215x102.5x65	2739	2732	**7**	40x215
	2	215x102.5x65	2761	2750	**11**	40x216
	3	215x102.5x65	2634	2624	**10**	40x217