

**PRODUCING LIGHT WEIGHT CONCRETE BY PARTIALLY REPLACING
COARSE AGGREGATE WITH PALM KERNEL SHELL**

BY

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SUBMITTED TO

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CERTIFICATION

This is to certify that this project topic titled producing light weight concrete by partially replacing coarse aggregate with palm kernel shell was carried out by Okocha Prosper Theophilus with registration number (NAU/2017224007) in the Department of Civil Engineering, Nnamdi Azikiwe University, Awka, Anambra State.

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APPROVAL PAGE

This research work “producing light weight concrete by partially replacing coarse aggregate with palm kernel shell” is an authentic academic work undertaken by Okocha Prosper Theophilus and is presented to the department of Civil Engineering, Faculty of Engineering, Nnamdi Azikiwe University Awka for approval in partial fulfillment of the requirement for the award of Bachelor of Engineering (B.Eng).

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DEDICATION

This work is dedicated to the owner of life, the creator of the universe, Almighty God for the gift of life and also for guiding me throughout my stay in school. I also dedicate this work to my lovely parents Pst/Pst Mrs. Okocha Theophilus, who serves as a real source of inspiration and support toward my academic pursuit.

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ABSTRACT

Recent increase in concrete production cost due to high cost of transportation of coarse aggregate to regions where the material is relatively scarce is a major source of concern to professionals in the building industry. Moreover, there are severe negative environmental impact associated with quarrying of limestone ranging from noise pollution, impaired air quality and emission of dust and particles into the atmosphere. The aforementioned problems have necessitated the exploration of environmentally friendly alternative for the production of concrete Uchechi, et al., (2017).

This study investigates the feasibility of producing lightweight concrete by partially replacing coarse aggregate with palm kernel shell (PKS). The main objective was to determine the effect of PKS on the mechanical and physical properties of concrete. The experiment involved mixing different proportions of PKS(say 5-20%) with traditional coarse aggregates in concrete mixtures for 1:2:4 mix ratio using 0.6 w/c ratio and testing the compressive strength, water absorption, workability and density of the resulting concrete also, to determine the proportion of palm kernel shell that can be found useful in the production of lightweight concrete. Fifteen cubes of concrete were casted for each percentage replacement including the control mix and tested for 7, 21 and 28days curing ages. It was discovered that 5% replacement of coarse aggregate with palm kernel shell gave the highest slump value apart from the control, while concrete mix with 20% PKS gave lowest slump value, this was because palm kernel shell absorbs more water than granite. Result from the experiment showed that the workability, density and the compressive strength of concrete decreased on addition of palm kernel shell as compared to control cubes.

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LIST OF SYMBOLS

SD	-	Sand
GT	-	Granite
PKS	-	Palm Kernel Shell
LWC	-	Lightweight concrete

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CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Nigeria is a developing country with limited level of infrastructural development. Continuous growth of infrastructure requires intensified development of infrastructures (buildings, tunnels, dams, roads, and embankment) that makes life easier and support modern society. One of the major components used for the development of the aforementioned infrastructure is concrete. Concrete is the world's most consumed man-made-material (Naik, 2008). Its great versatility and relative economy in filling wide range of needs has made it a competitive building material (Sashidar and Rao, 2010). Concrete production is not only a valuable source of societal development, but it is also a significant source of employment. (Naik, 2008).

Concrete is a composite mixture of fine aggregate (sand), coarse aggregate (granite), water and cement in their correct proportion. Coarse aggregate (granite) functions as economic fillers and contribute significantly to the durability of the hardened concrete. These aggregate are produced during quarrying of limestone especially in regions where limestone is present in substantial quantities. Recent increase in concrete production cost due to high cost of transportation of coarse aggregate to regions where the material is relatively scarce is a major source of concern to professional in the building industry. Moreover, there are severe negative environmental impact associated with quarrying of limestone ranging from noise pollution, impaired air quality and emission of dust and particles into the atmosphere. The aforementioned problems have necessitated the exploration of environmentally friendly alternative for the production of concrete Uchechi, et al., (2017).

Many agricultural and industrial by-products recognized as potential replacement of conventional aggregate in concrete are light weight aggregate Uchechi, et al., (2017). Advantages of light weight aggregate concrete over conventional concrete include decreased dead load, lower rate of depletion of natural resources, lower thermal conductivity, and reduced construction costs. There is a continuing trend towards the use of more lightweight concrete in applications such as prestressed concrete and high-rise buildings (Neville and Brooks, 2010). Some agricultural by-products such as palm kernel shell have been identified as potential

replacement aggregate in concrete. However, agricultural by-products have not been fully utilized as coarse aggregates in building sustainable concrete structures in Nigeria.

Palm fruit and nut are the principal source of edible oil, a major cooking ingredient in the Southern parts of Nigeria. Palm oil trees thrive in the tropics and are found in tropical regions of Africa, Asia, and America. According to Alengaram, et al, (2010), Palm kernel shells (PKS) are organic waste materials obtained from crude palm oil producing factories in Asia and Africa. The Palm Oil Plant (*Elaeis Guinensis*), considering its three different varieties Dura, Pesipher and Tenera produces an edible fruit similar to an apricot which has a nut inside. During the crude palm oil process, the fruit's flesh is melted through a steaming treatment. The residual nuts are further mechanically crushed to extract the seeds or kernels. The Palm Kernel Shells (PKS) is a virgin biomass with a high calorific value, typically about 3,800 Kcal/kg (ASTM, 1978). Oil Palm trees grow in the coastal belt in Nigeria and in riverine belt which follows the valleys of Niger and Benue for a distance of about 450 miles from the sea Oyejobi, et al., (2012). The main palm oil producing states include Ogun, Ondo, Oyo, Edo, Cross River, Anambra, Enugu, Imo, Abia, Ekiti, Akwa-Ibom, Delta and Rivers, Oyejobi, et al., (2012).

In other to reduce concrete production cost resulting from cost of transporting coarse aggregate and also reduce the negative impact of quarrying of limestone on the environment, this study will therefore evaluate the mechanical properties of concrete produced with partial replacement of coarse aggregate with palm kernel shell.

Palm fruit

Palm fruit. *Elaeis* (from Greek 'oil') is a genus of palms containing two species, called oil palms. They are used in commercial agriculture in the production of palm oil. The African oil palm *Elaeis guineensis* (from Guinea) is the principal source of palm oil.

Palm kernel/palm nut

The palm kernel is the edible seed of the oil palm fruit. The fruit yields two distinct oils: palm oil derived from the outer parts of the fruit, and palm kernel oil derived from the kernel

Palm kernel shell

Palm kernel shell is a hard fibrous material that encloses the nut or seed of the palm kernel. It is a waste product obtained after the processing of palm kernel. Palm kernel is enclosed in the shell. The shell is also enclosed in fleshy fiber, which contains palm oil. Thus palm kernel shell is obtained when the fibrous, fleshy fruit has been processed to obtain palm oil.

1.2 Statement of Problem

There is a growing need to ensure rational use of earth resource in the production of concrete. Concrete production incorporate the use of fine aggregate (sand), coarse aggregate (granite), cement and water in their correct proportion. Coarse aggregate as one of the components of concrete is produced during quarrying of limestone. There are severe negative environmental impact associated with quarrying of limestone ranging from noise pollution, impaired air quality and emission of dust and particles into the atmosphere. Moreover, cost of concrete production have risen significantly as a result of high cost of transportation of coarse aggregate to regions where the material are present in negligible quantities. These developments have necessitated the exploration of environmentally friendly alternatives for production of concrete. The utilization of agricultural by-product as a partial replacement for coarse aggregate in the production of concrete constitutes a viable option.

This study will therefore explore the use of palm kernel shell as an alternative for production of light weight concrete.

1.3 Aim and Objectives of Study

The aim of the study is to evaluate the effect of partial replacement of coarse aggregate with palm kernel shell (PKS) on certain properties of light weight concrete while the objectives include:

- 1 To ascertain the efficacy and feasibility of palm kernel shell as a partial substitute of coarse aggregate in concrete.
- 2 To partially replace coarse aggregate with palm kernel shell and evaluate it effect on compressive strength with that of corresponding normal concrete.
- 3 To determine the change in weight of palm kernel shell concrete when compared to corresponding normal concrete.

- 4 Draw conclusion and make relevant recommendation based on key research findings.

1.4 Scope of Study

The scope of the study is entirely on light weight concrete produced with partial replacement of coarse aggregate with palm kernel shell. Laboratory testing for the components of concrete and additive (palm kernel shell) includes: Sieve analysis test, Specific gravity test, Water absorption test and Bulk and Compacted density test. Test to be carried out for the conventional (corresponding normal concrete) and non-conventional (palm kernel shell) concrete are compressive strength of the hardened concrete and slump of the fresh concrete. The curing of the concrete is entirely by outer immersion other method of curing will not be used. Result obtained from density and compressive strength test will be used as bases for making conclusion and recommendation.

1.5 Significance of Study

This research will investigate the use of palm kernel shell as a partial substitute for coarse aggregate in concrete and findings obtained from the experimental study will be significant in the following ways:

- 1 Ensure rational use of earth resources in the production of concrete.
- 2 Ensure environmental protection through reduction in noise and dust and particle emission associated with quarrying of limestone during production of coarse aggregate.
- 3 Reduce overall concrete production cost.
- 4 Facilitate high rate of construction work.
- 5 Mitigate waste management problems in both rural and urban areas through reduction in volume of agricultural waste (palm kernel shell) generated.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

Concrete is the most versatile heterogeneous construction material and the most valuable construction material for infrastructural development of any nation. Civil engineering practice and construction works around the world depend to a very large extent on concrete. Concrete is a synthetic construction material made by mixing cement, fine aggregates, coarse aggregates and water in the proper proportions. Aggregates serve as inert filler materials while at the same time improving concrete workability, volume stability and durability. Recent studies (Alengaram et al., 2013; Yap et al., 2013; Williams et al., 2014; Itam et al., 2016) have shown the suitability of palm kernel shell (PKS) in concrete production as coarse aggregate replacement. Concrete may be defined as a composite material consisting of a binding material, water, fine and coarse aggregates, and in some instances, the incorporation of admixtures all in definite proportions to achieve a desired property. The binding material in most instances is the Ordinary Portland Cement (OPC) although other binding materials are also in use. Concrete is an artificial material comparable in appearance and properties to some natural lime stone rock. It is a man-made composite, the major constituent being natural aggregate such as gravel, or crushed rock, sand and fine particles of cement powder all mixed with water. The concrete as time goes on through a process of hydration of the cement paste, producing a required strength to endure the load (Maninder and Manpreet, 2012).

The density and compressive strength of concrete are one of the most useful properties of concrete. In most structural applications, concrete is employed primarily to resist compressive strength stresses. In case where strength in tension or in shear is of primary importance, the compressive strength is frequently used as a measure of these properties. Therefore the concrete making properties of various ingredients of mix are usually measured in terms of the compressive strength. Compressive strength is also used in a qualitative measure for other properties of a hardened concrete. The compressive strength is determined by testing cubes or cylinders in the laboratory. The strength of a concrete is its resistance to rupture. It can be measured in a number of ways: strength compression in tension, in shear or in flexures. The cohesion and internal friction developed by concrete in resisting failure is related to the water-

cement ratio, the design constituents, the mixing, placement and curing methods employed. There is a need to explore alternative material for concrete production in such a way that the concrete mechanical properties especially the compressive strength is not undermined. This section will therefore review relevant literature on the production of light weight concrete with partial replacement of coarse aggregate with palm kernel shell.

2.2 History of Concrete

The first major concrete users were the Egyptians in around 2,500BC and the Romans from 300BC the Romans found that by mixing sandlike material which they obtained from Pozzuoli with their normal lime-based concretes they obtained a stronger material. The pink sand turned out to be fine volcanic ash and they had unintentionally produced the first pozzolanic cement. Pozzolanic is any siliceous and aluminous material which possesses little or no cementitious value in itself but will, if finely divided and mixed with water, chemically react with calcium hydroxide to form compounds with cementitious properties.

2.3 Classification of Concrete

2.3.1 Classification of concrete by strength

2.3.1.1 Low strength concrete

A weak concrete is considered generally anything with a characteristic compressive strength of below 20MPa or N/mm².

2.3.1.2 Moderate strength concrete

A moderate strength concrete is defined as concrete with compressive a strength between 20MPa to 50MPa.

2.3.1.3 High strength concrete

A high strength concrete is defined as concrete with a compressive strength between 50 to 200MPa

2.3.1.4 Ultra high strength concrete

Ultra high strength concrete is defined as concrete with a compressive strength above 220MPa.

2.3.2 Classification of concrete by weight

2.3.2.1 Ultra-light concrete

Ultra-light Weight Concrete is created with the addition of either polystyrene beads (nonstructural) or a lightweight aggregate (structural) to the formula. Although both formulations are lightweight products, they have several important differences that make each one suitable to specific projects. Ultra-light weight concrete has a density less than 1,200kg/m³

.The present study presents a methodology to design ultra-lightweight concrete that could be potentially applied in monolithic concrete structures, performing as both load bearing element and thermal insulator.

2.3.2.2 Normal weight concrete

The nominal weight of normal concrete is 144 lb / ft³ for non-air-entrained concrete, but is less the air-entrained concrete. (The weight of concrete plus steel reinforcement is often assumed as 150lb / ft³). Strength for normal-weight concrete ranges from 2000 to 20,000 psi. It may be used for concrete paving mixes. It can be produced with many variable characteristics including strength, fluidity, colour and weight.

2.3.2.3 Heavy weight concrete

Concretes made with heavyweight aggregates are used for shielding and structural purposes in construction of nuclear reactors and other structures exposed to high intensity radiation.

Heavyweight aggregates are used where heavyweight is needed, such as ship's ballast and encasement of underwater pipes, and for making shielding concretes because absorption of such radiation is proportional to density, and consequently, these aggregates have greater capacity for absorption than those ordinarily used for normal concrete. With such aggregates, concrete

weighing up to about 385 lb/ft³ can be produced. Concrete made with limonite or magnetite can develop densities of 210 to 224 lb/ft³

And compressive strengths of 3200 to 5700 psi. With barite, concrete may weigh 230 lb/ft³ and have a strength of 6000 psi. With steel punching and sheared bars as coarse aggregate and steel shot as fine aggregate, densities of 250 to 288 lb/ft³ and strengths of about 5600 psi can be attained.

Generally, grading of aggregates and mix proportions are similar to those used for normal concrete. The properties of heavyweight concrete are similar to those of normal-weight concrete. Mixing and placing operations, however, are more difficult than those for normal-weight concrete, because of segregation.

Good grading, high cement content, low W/C, and air entrainment should be employed to prevent segregation. Sometimes, heavyweight aggregates are grouted in place to avoid segregation. Heavyweight concretes usually do not have good resistance to weathering or abrasion.

2.3.2.4 Lightweight Concrete

Lightweight concrete is a mixture made with lightweight coarse aggregates such as shale, clay, or slate, which give it its characteristic low density. Structural lightweight concrete has an in-place density of 90 to 115 lb/ft³, whereas the density of regular weight concrete ranges from 140 to 150 lb/ft³. This makes lightweight concrete ideal for building modern structures that require minimal cross sections in the foundation. It is being increasingly used to build sleek foundations, and has emerged as a viable alternative to regular concrete.

The lightweight is due to the cellular or high internal porous microstructure, which gives this type of aggregate a low bulk specific gravity. The most important aspect of lightweight aggregate is the porosity. They have high absorption values, which requires a modified approach to concrete proportioning. For instance, slump loss in lightweight concrete due to absorption can be an acute problem, which can be alleviated by pre-wetting (but not saturating) the aggregate before batching. Lightweight concrete is a cost effective alternative to normal concrete, especially since it does not compromise on the structure's strength. The higher porosity of LWC also influences its thermal conductivity, making it suitable for projects that require insulation from heat damage.

Nevertheless, a higher compressive strength of 7000 to 10,000 psi can be attained with lightweight concrete. However, this may compromise the density of the mixture as it requires the addition of more pozzolans and water-reducing admixtures to the concrete.

2.3.2.4.1 Differences between Normal and Lightweight Concrete

In contrast to traditional concrete, lightweight concrete has higher water content. The use of porous aggregates increases the time it takes to dry; hence, to offset this problem, aggregates are pre-soaked in water before being added into the cement.

As mentioned earlier, normal concrete can weigh between 140 to 150 Lbs/ft³ due to the presence of denser aggregates in their natural state. As a result, many believe normal concrete to be cheaper compared to LWC. However, projects made with normal concrete require additional material for framing, cladding, and steel reinforcements – ultimately increasing the overall cost. Hence, LWC remains a cost effective construction material, especially for larger projects.

2.3.2.4.2 Practical Applications of Lightweight Concrete

One of the most popular structures built with lightweight concrete is the Bank of America Building in Charlotte, N.C. This shows how LWC can be used to build formidable structures, especially since the possibility of dead load being transferred from one floor to the next is greatly reduced.

LWC is thus ideal for constructing additional flooring on top of older or even newer structures, as it reduces the risk of collapse. As such, it can be used to successfully build bridges, decks, girders, piers, precast constructions, and high rise buildings with reduced density. For example, utilizing LWC in the Wabash River Bridge allowed builders to reduce project density by 17%, and save 18% in terms of cost – amounting to a whopping \$1.7 million.

Due to LWC's low thermal conductivity and higher heat resistance, it is now commonly used to insulate water pipes, walls, rooftops, etc. It guards against steel corrosion by forming a protective layer, which also works to insulate steel structures against rot. LWC is also commonly used to construct interstate and traffic lanes, without adding dead load to existing structures.

2.3.2.4.3 Types of Lightweight Concrete

Lightweight aggregate concrete

This form of lightweight concrete is produced using porous and lightweight aggregates including Clay, Shale, Slate, Volcanic Pumice, Ash, or Perlite. Weaker aggregates may also be added to the mixture, which has an impact on its thermal conductivity; however, doing so may reduce its strength.

Lightweight aggregate is perfect for pre-cast concrete blocks or steel reinforcements. However, denser varieties show better bonding results between steel and concrete, along with enhanced protection from steel corrosion.

Aerated or foamed concrete

This type of lightweight concrete is also known as gas concrete or foamed concrete, since it is developed by introducing large voids into the mortar mass or concrete. Voids are typically injected through a chemical reaction, or with the use of an air entraining agent.

Aerated or foamed concrete does not require flattening, exhibits appropriate thermal insulation, and is self-compacting. This makes it ideal for use in hard to reach spaces and sewer systems.

No-fines concrete

This form of concrete is developed by eliminating fine aggregates from the mixture; resulting in concrete which comprises of only large voids and coarse aggregates. This is why No-Fines concrete has better insulation and relatively reduced drying shrinkage.

No-Fines concrete is best-suited for load bearing walls and can be used for both indoor and outdoor constructions. However, this type of lightweight concrete should not be used with reinforced concrete, especially due to its lower density and cement content.

2.3.2.4.4 Pros & Cons of Lightweight Concrete

Lightweight concrete is a flexible and easily transportable building material, and requires little support from materials such as steel or additional concrete. This makes it cost effective, especially for larger building projects.

Additionally, due to its low thermal conductivity and fire resistance, LWC is an ideal material for insulating against heat damage.

Despite its reduced density, structures built with LWC are unlikely to collapse. In fact, LWC is less likely to shrink compared to normal concrete and also shows increased resistance to rot and termite infestations.

However, LWC also has a few limitations. Since it has higher water content, it takes longer to dry out. Moreover, adding too much water can result in the formation of laitance layers, while compromising on water to offset this limitation may result in a weaker mixture.

Since LWC is also highly porous, it is difficult to place the mixture correctly. Another issue with LWC is that the cement tends to separate from aggregates if mixed incorrectly.

In a nutshell

Lightweight concrete is a cost effective alternative to normal concrete, especially since it does not compromise on the structure's strength. The higher porosity of LWC also influences its thermal conductivity, making it suitable for projects that require insulation from heat damage.

2.4 Concrete Production Process

2.4.1 Batching

The correct measurement of the various materials used in the concrete mix is called batching. Errors in batching are partly responsible for the variation in the quality of concrete. Concrete can be batched in two ways:

- a) By volume batching and
- b) By mass (weight) batching

Weigh-batching of materials is always preferred to volume batching. When weigh-batching is not possible and the aggregates are batched by volume, such volume measures to be regularly checked for the weight-volume ratio.

2.4.2 Mixing

This is the practical means of producing fresh concrete and placing it in the form so that it can harden into the structural or building material referred to as concrete'. The sequence of operation is that the correct quantities of cement, aggregates and water, possibly also admixture are batched and mixed in a concrete mixer which produces fresh concrete. This is transported from the mixer to its final location. The fresh concrete is then placed in the forms, and compacted so

as to achieve a dense mass which is allowed and helped, to harden. The objective of mixing of concrete is to coat the surface of all aggregate particles with cement paste and to blend all ingredients of concrete into a uniform mass. Mixing of concrete is done either by hand or by machine. Mixers performances shall be checked for conformity to the requirements of the relevant standards. Concrete shall be mixed for the required time; both under-mixing and over-mixing shall be avoided.

2.4.3 Transportation

After mixing, concrete shall be transported and placed at site as quickly as possible without segregation, drying, etc. as soon as concrete is discharged from the mixer, internal as well as external forces starts acting to separate the dissimilar constituents. If over-weight concrete is confined in restricting forms, the coarser and heavier particles tend to settle and finer and lighter materials tend to rise. If concrete is to be transported for some distance over rough ground the runs shall be kept as short as possible since vibrations of this nature can cause segregation of the materials in the mix. For the same reason concrete should not be dropped from a height of more than 1m. If this is unavoidable a chute shall be used. The green concrete shall be handled, transported and placed in such a manner that it does not get segregated. The time interval between mixing and placing the concrete shall be reduced to the minimum possible.

2.4.4 Placing

The formwork and position of reinforcement shall be checked before placing concrete to make sure that they are clean and free of any detritus, such as ends of tying wire. The fresh concrete shall be deposited as close as possible to its ultimate position. Care need to be taken when discharging concrete from skips to avoid dislodging the reinforcement or over filling the formwork. When filling columns and walls, care shall be taken that the concrete does not strike the face of the formwork, which might affect the surface finish of the hardened concrete. For deep sections the concrete shall be placed in uniform layers, typically not more than about 500 mm thick, each layer being fully compacted.

2.4.5 Compaction

Compaction of concrete is the process adopted for expelling the entrapped air form the concrete. In the process of placing and mixing of concrete, air is likely to get entrapped in the concrete. If

this air is not detrained out fully, the concrete losses strength considerably. Anticipated targets of strength, impermeability and durability of concrete can be achieved only by thorough and adequate compaction. One per cent of the air voids left in concrete due to incomplete compaction can lower the compressive strength by nearly five percent (Gambhir, 2004).

2.4.6 Curing

Curing of concrete is the process of maintaining satisfactory moisture content and a favorable temperature in concrete during the period immediately after the placement of concrete so that hydration of cement may continue till the desired properties are developed sufficiently to meet the requirements of service. The reasons for curing concrete are to keep the concrete saturated or as nearly saturated as possible, until the originally water filled space in the fresh cement paste has been filled to the desired extent by the product of hydration of cement, to prevent the loss of water by evaporation and to maintain the process of hydration, to reduce the shrinkage of concrete and to preserve the properties of concrete. Concrete derives its strength by the hydration of cement particles. The hydration of cement is of momentary action but a process continuing for a long time. The rate of hydration is fast to start with but continues over a long time at a decreasing rate. Curing is usually requires for at least 7 days after the day the concrete is placed, this may vary in certain special circumstances (Onwuka and Omerekpe, 2003). Adequate curing is essential for the handling and development of strength of concrete. The curing period depends upon the shape and size of member, ambient temperature and humidity conditions, type of cement, and the mix proportions. Nevertheless, the first week or ten days arc the most critical, as any drying out during this young age can cause irreparable loss in the quality of concrete. Generally, the long-term compressive strength of concrete moist cured for only 3 days or 7 days will be about 60 per cent and 80 per cent, respectively, of the one moist cured for 28 days or more (Gambhir, 2004).

2.4.7 Formwork

Formwork is a structure, usually temporary, used to contain poured concrete and to mould it to the required dimensions and support until it is able to support itself. It consists primarily of the face contact material and the bearers that directly support the face contact material. Proper

removal of formwork is an important factor to achieve good quality of concrete during the service life.

2.4.8 Inspection and Testing

Inspection and testing play a vital role in the overall quality control process. Inspection could be of two types, quality control inspection and acceptance inspection. For repeated operations early inspection is vital, and once the plant has stabilized, occasional checks may be sufficient to ensure continued satisfactory results. The operations which are not of repetitive type would require, on the other hand, more constant scrutiny. Apart from the tests on concrete materials, concrete can be tested both in the fresh and hardened states. The tests on fresh concrete offer some opportunity for necessary corrective actions to be taken before it is finally placed. These include tests on workability, unit weight or air content (if air-entrained concrete is used).

2.5 Constituents of Concrete

Chudley and Greeno, (2006) assert that the proportions of each of concrete materials control the strength and quality of the resultant concrete. Fresh concrete is a plastic mass, which can be moulded into any desired shape. This is its main advantage as a construction material (Gupta and Gupta, 2004). They further assert that aggregate, coarse and fine combined occupy about 70% space in a given mass of concrete and the rest 30% space is filled by water, cement and air voids. Bert-Okonkwo, (2012) in his definition described concrete as a mixture of Portland cement, fine aggregate coarse aggregate, air and water. Sharma, (2008) concludes in stating that concrete is a heterogeneous mix consisting of the following materials: cement, aggregate (coarse and fine), water and admixture (when necessary). Below are descriptions of some of these components of concrete.

2.5.1 Cement

Cement is a binder material, a substance made of burned lime and clay which after mixing with water, set and harden independently and can bind other materials together Ezeokonkwo, (2014). According to (Onwuka and Omerekpe, 2003), cement as a hydraulic binders react exothermically with water to form hard strong masses with extremely low solubility. They consist of chemical compounds such as calcium silicate and calcium aluminates. Cement is a cementitious material

which has adhesive and cohesive properties necessary to bound inert aggregates into a solid mass of adequate strength and durability. Neville, (1993) also adds that cement is the binding material constituent of concrete which reacts chemically with water and aggregate to form a hardened mass on hydrating. Iheama, (2010) further defines it as a finely pulverized product resulting from calcination of natural argillaceous limestone at a temperature below the fusion. In addition to this Ivor, (1995), defines cement as a mixture of compounds, consisting mainly of silicates and aluminates of calcium, formed out of calcium oxide, silica, aluminium oxide and iron oxide. Hydraulic cements are of four types: Portland cement, Blended Portland Cement, and Portland cement with additives and High Alumina Cement. Cement varying chemical composition and physical characteristics exhibit different properties on hydration. The cement of desired properties can be produced by selecting suitable mixture of raw materials. The various types of Portland cement used in the construction industry are: Ordinary Portland Cement(OPC), Rapid Hardening Portland Cement(RHPC), Sulphate resisting Portland Cement(SRPC), Low Heat Portland Cement(LHPC), Blast Furnace Portland Cement(BFPC), Portland Pozzolana Cement(PPC), Modified Portland Slag Cement(MPC).

Many authors (Ezeokonkwo, 2014: Anosike, 2010: Gupta and Gupta, 2004: Iheama, 2010) agreed to the fact that on the addition of water to cement, hydration takes place, liberating a large quantity of heat. On hydration of cement, the gel is formed which binds the aggregate particles together and provides strength and water tightness to concrete on hardening. Thus cement has the property of setting and hardening underwater by a chemical reaction with it. Portland cement is a substance which binds together the particles of aggregates (usually sand and gravel) to form a mass of high compressive strength concrete. It is a combination of limestone or chalk with clay mixed in a proportion depending on the type of cement desired. Portland cement is the most common type of cement generally used around the world because it is a basic ingredient of concrete, mortar and stucco. It is a fine powder produced by grinding Portland cement clinker more than 90%, and a limited amount of calcium sulphate which controls the set time. Portland cement clinker is a hydraulic material which consist at least two-thirds by mass of calcium silicates ($3\text{CaO}\cdot\text{SiO}_2$ and $2\text{CaO}\cdot\text{SiO}_2$).

Okereke, (2003), Portland cement is manufactured by firing a controlled mixture of chalk or limestone (CaCO_3) and substances containing silica and alumina such as shale in a kiln at 1500°C temperature. They are heated to clinker and grounded to a fine powder with a small proportion of

gypsum (calcium sulphate) which regulates the rate of setting when the cement is mixed with water. Anosike, (2010) also states that the manufacture of PC consists of the following three distinct processes: Mixing, Burning and Grinding. Mixing can be done by dry-process or wet-process. The wet process is the most common. The main difference between the wet and dry production process is the larger amount of water expelled from the kiln during the production process.

2.5.1.1 Chemical Composition of Portland Cement

Anosike, (2010), the ordinary and rapid hardening PC can be tested by the methods given in I.S. 4032. The results of the tests should comply with the following chemical requirements:

- a) The ratio of the percentage of lime to the percentage of silica, alumina and ironoxide when calculated by the following formula:

$$\frac{\text{CaO} - 0.7\text{SO}_3}{\text{SiO}_2 + 1.2\text{Al}_2\text{O}_3 + 0.65 \text{Fe}_2\text{O}_3}$$

It should be between 0.66 and 1.02.

- b) The Ratio of the percentage of alumina to iron oxide should not be less than 0.66.
 c) Weight of insoluble residue should not be more than 2%.
 d) Weight of magnesia should not exceed 6%.
 e) Total sulphur content calculated as sulphuric anhydride (SO₃) should not exceed 2.75 or 3.0%.
 f) Total loss of ignition should not be more than 2%.

According to Shetty, (2005), the raw materials used in the manufacture of Portland cement consist mainly of lime (CaO), silica (SiO₂), alumina (Al₂O₃) and iron oxide (Fe₂O₃). The four compounds are usually regarded as the major constituents of cement. They are described in abbreviated form by cement chemists as follows: CaO = C; SiO₂ = S; Al₂O₃ = A; and Fe₂O₃ = F. Likewise, H₂O in hydrated cement is denoted by H, and SO₃ by S. In addition to the main compounds listed above, there exist minor compounds, such as MgO, TiO₂, Mn₂O₃, K₂O and Na₂O; they usually amount to not more than a few per cent of the mass of cement. Two of the minor compounds are of particular interest: the oxides of sodium and potassium, Na₂O and K₂O, known as the alkalis. They have been found to react with some aggregates, the products of the reaction causing disintegration of the concrete, and have also been observed to affect the rate of

the gain of strength of cement (Neville, 2005). The relative proportions of these oxide compositions are responsible for influencing the various properties of cement; in addition to rate of cooling and fineness of grinding. Table 2.0 shows the approximate oxide composition limits of ordinary Portland cement.

Table 2.0 Oxide Composition Limit of Ordinary Portland Cement (OPC) (Shetty, 2005).

Oxide	Approximate Percentages
CaO	60-67
SiO ₂	17-25
Al ₂ O ₃	3.0-8.0
Fe ₂ O ₃	0.5-6.0
MgO	0.1-4.0
Alkalis(K ₂ O, N ₂ O)	0.4-1.3
SO ₃	1.3-3.0

The oxides present in the raw materials when subjected to high clinkering temperature combine with each other to form complex compounds. The identification of the major compounds is largely based on R.H. Bogue's work and hence it is called —Bogue's Compounds. The four compounds usually regarded as major compounds are tricalcium silicate (C₃S), dicalcium silicate (C₂S), tricalcium aluminate (C₃A) and tetracalciumalumino ferrite (C₄AF). Shetty, (2005).The Bogue's formula used in calculating the percentage of the various compounds is given as follows: C₃S = 4.07 (CaO) – 7.60 (SiO₂) – 6.72 (Al₂O₃) – 1.43 (Fe₂O₃) – 2.85 (SO₃)
 C₂S = 2.87 (SiO₂) – 0.754 (3CaO.SiO₂)
 C₃A = 2.65 (Al₂O₃) – 1.69 (Fe₂O₃)
 C₄AF= 3.04 (Fe₂O₃).

2.5.1.2 Properties of Cement

a) Fineness of Cement

Fineness is a vital property of cement which influences the rate of reaction of cement with water (hydration). The fineness of the cement affects the rate of hydration. It also affects its place ability, workability and water content of a concrete mix much like the amount of cement used in concrete. For a given weight of a finely ground cement, the surface area of the particles is greater than for a coarsely ground cement. The advantages of finer cement include:

- a) Increases the rate of hydration
- b) More rapid and greater strength development,
- c) Reduced bleeding rate of concrete
- d) Improving the workability of concrete

The fineness of cement has an important bearing on the rate of hydration and hence on the rate of gain of strength and also on the rate of evolution of heat. Finer cement offers a greater surface area for hydration and hence fastens the development of strength. Fineness of cement is determined by permeability. For example in the blaine air permeability method, a known volume of air is passed through cement. The time is recorded and the specific surface is calculated by a formula. Fineness is expressed in terms of specific surface of the cement (Cm^2/gr). For OPC specific surface area is 2600-3000 Cm^2/gr . This test is conducted as per BS EN196-6:1995.

Neville and Brooks, (2004), three methods of determining the fineness of cement are by sieve analysis, by specific surface area method and by LEA and nurse method.

b) Soundness of Cement

Soundness is referred to as the volume stability of cement paste. The cement paste should not undergo large changes in volume after it has set. Free CaO and MgO may result in unsound cement (Chanadan. 2019). Upon hydration, C and M (calcium and magnesium) will form CH and MH with volume increase thus cracking. (Gartener, et al. 1989), since unsoundness is not apparent until several months or years, it is necessary to provide an accelerated method for its determination which includes:

- a) Lechatelier Method where only free CaO can be determined.
- b) Autoclave Method where both free CaO and MgO can be determined.

In the soundness test a specimen of hardened cement paste is boiled for a fixed time so that any tendency to expand is sped up and can be detected. Soundness means the ability to resist volume expansion. For ordinary Portland cement, BS-EN 197 part1 (2000) has specified a maximum expansion of 10mm. The work of Chowdhury et al., (2015) indicated that the soundness of cement was improved with the addition of saw dust ash as partial replacement. In the research, cement was replaced by the ash within the range of 5% to 30% and the soundness was found to increase with an increase in the ash content.

c) Setting Time of Cement

Setting time refers to a change from liquid state to solid state. During setting time, cement paste acquire some strength (Gartener, et al. 1989). The water content has a marked effect on time of setting. In acceptance test for cement, the water content is regulated by bringing the paste to a standard condition of wetness and this is referred to as “normal consistency”. Normal consistency of OPC ranges from 20-30% by weight of concrete. Vicat apparatus is used to determine normal consistency. Normal consistency is that condition for which the penetration of a standard weighed plunger into the paste is 10mm in 30sec. In practice, the terms initial set and final set are used to describe arbitrary chosen time of setting. Initial set indicates the beginning of a noticeable stiffening and final set may be regarded as the start of hardening (or complete loss of plasticity). It is the also the period between the time water is added to cement and time at which 1 mm square section needle fails to penetrate the cement paste, placed in the Vicat’s mould 5 mm to 7 mm from the bottom of the mould. Final setting time is that time period between the time water is added to cement and the time at which 1 mm needle makes an impression on the paste in the mould but 5 mm attachment does not make any impression. The setting time test is carried out using the Vicat apparatus as per BS-EN 196 part3 (1995). The results of the test should comply with the requirements of BS-EN 197 part1 (2000), which recommend a minimum of 60 minutes and a maximum of 10 hours as the initial and final setting times of ordinary Portland cement respectively. (Gartener, et al. 1989) summarized the factors affecting setting time as:

- a) Temperature and Humidity.
- b) Amount of water
- c) Chemical composition of cement

d) Fineness of cement (the finer the cement, the faster the setting)

Marthong, (2012), investigated that the addition of saw dust ash in OPC grade 42.5 had increased the initial and final setting times. This was attributed to the low rate of hydration in the paste containing the saw dust ash.

2.5.2 Aggregate

Ezeokonkwo, (2014), the term aggregate includes the natural sand, gravels and crushed stone used in making concrete. Bert-Okonkwo, (2012) describes the term aggregate, as inert materials like gravel, crushed stones, broken bottles which are mixed with cement and water to make concrete. (Merritt, 1983: Rangwala, 2005), in their contribution describe aggregates as inert or chemically inactive materials which form the bulk of concrete and are bound together using cement as a binder. In any concrete, aggregates (fine and coarse) usually occupies about 70-75% (Gupta and Gupta, 2004: Neville and Brooks, 2004). The aggregates have to be graded so the whole mass of concrete acts as a relatively solid, homogeneous, dense combination with the smallest particles acting as inert filler for the voids that exist between the larger particles (Nawy, 2002). This statement gives us the suggestion that the selection and proportioning of aggregates should be given due attention as it not only affects the strength but the durability and structural performance of the concrete also.

Aggregates are considered clean if they are free of excess clay, silt, mica, organic matter, chemical salts and coated grains Ezeokonkwo, (2014). In addition to that, (Merritt, 1983: Rangawala, 2005: Neville, 1993), support the idea that an aggregate should be physically sound if it retains dimensional stability under temperature or moisture change and resists weathering without decomposition. Ezeokonkwo, (2014) concludes that for an aggregate to be considered adequate in strength, aggregate should be able to develop the full strength of the cementing matrix. Anosike, (2010), aggregates provide better strength, stability and durability to the structure made out of cement concrete than cement paste alone.

Aggregate is not truly inert because its physical, thermal and chemical properties influence the performance of concrete. While selecting aggregate for a particular concrete, the economy of the mixture, the strength of the hardened mass and durability of the structure must first be considered (Gupta and Gupta, 2004).

2.5.3 Water

Water used in the concrete reacts with cement and causes it to set and harden. It also facilitates mixing, placing and compacting of fresh concrete. Abruckle, (2007), states that mixing water for concrete is required to be fit for drinking or to be taken from an approved source. Findings in previous works (Ezeokoko, 2014: Bert-Okonkwo, 2012: Neil and Ravrinda, 1996) suggest that, to achieve the required workability and strength of concrete in both its fresh and hardened state, the water used for mixing and curing needs to be of appropriate quality, that is, it should be free from impurities such as suspended solids, organic matter and salts which may adversely affect the setting, hardening, strength and durability of the concrete.

Water is used in the production of concrete, washing of aggregates, mortar and bricks formation. Water is also used for construction operations like casting, painting, terrazzo finishing, plastering and other operations. After casting of concrete, water is poured on the concrete to give it strength in a process known as curing. After completion of the building, water is used for cleaning the building in readiness for inspection, handing-over and occupancy. As a result of these facts, it is obvious that water is very important in building construction and related activities. Neil and Ravindra, (1996) further define water to cement ratio (w/c) as the weight of water divided by the weight of cement.

According to (BS8110: Part 1, 1997), the amount of water required in a concrete mix is the minimum for complete hydration of cement. If such concrete is fully compacted without segregation, it would develop the maximum attainable strength at a given age. The BS8110, (1997) further states that the water-cement ratio of approximately 0.25 weight is required for full hydration of cement. Omuvwie and Mosaku, (2010) suggest that if the water is not properly managed, it can turn around to inflict serious structural damage to the building over time and that such damage can lead to structural failure of the building and eventual collapse aside of the economic drain on client, safety risks as well as aesthetic devaluation.

2.5.4 Admixture

Admixtures are not a primary constituent of concrete. They are added to concrete if necessary and not all the time. Brantley and Brantley, (2004) admixtures are those chemicals that can be added to the concrete mix to achieve special purposes or meet certain construction conditions. Admixtures are mixed into the concrete to change or alter its properties.

The use of admixtures should offer improvement in the properties of concrete by adjusting the proportions of cement and aggregates. However, it should not affect adversely any property of concrete. An admixture should be used only after assessing its effect on the concrete to be used under an intended situation. It should also be known that admixtures are no substitute for good workmanship i.e. the effect of bad workmanship cannot be improved by the use of admixtures.

Gupta and Gupta, (2004) and Anosike, (2010) suggest that admixtures perform the following functions:

- a) Accelerate the initial setting and hardening of concrete.
- b) Retard the initial setting of concrete
- c) Increase the strength of concrete
- d) Improve the workability of fresh concrete
- e) Improve the durability of concrete
- f) Reduce the heat of evaluation
- g) Control the alkali-aggregate expansion
- h) Aid in the curing of concrete
- i) Improve wear resistance to concrete
- j) Reduce shrinkage during the setting of concrete

Bamibgoye et al., (2016) undertook particle size distribution analysis, slump test and compressive strength on hardened concrete in exploiting economics of gravel as a substitute to granite in concrete production. Sulymon et al. (2017) reported that sources of gravel greatly influence compressive, flexural and split-tensile strength of concrete David, et al., (2018).

2.6 Quality of Concrete

Quality means excellence. It is thus a philosophy rather than a mere feature. The difference between two objects is judged by their qualities. We set some standards those can determine the level of acceptability. In most industries especially in manufacturing and processing, the concept of quality control is old and used extensively.

Nowadays, application of quality control is not only becoming popular but also mandatory in construction industry. Just knowing some quality control methods or procedures will not do any good. We must have to adopt and implement the quality control methods and tools that are

available to us. The concept and its practice must be tuned in harmoniously. Quality control in construction activities guides the implementation of correct structural design, specifications and proper materials ensuring that the quality of workmanship by the contractor /sub-contractor is achieved.

2.6.1 Factors Affecting Quality of Concrete

In view of the different processes involved in the manufacture of concrete, the problems of quality control are diversified and their solution elaborated. The factors involved are the personnel, the materials and equipment, the workmanship in all stages of concreting, i.e. batching of materials, mixing, transportation, placing, compaction, curing, and finally testing and inspection. It is therefore necessary to analyze the different factors causing variations in the quality and the manner in which they can be controlled.

2.6.1.1 Materials

For a uniform quality of concrete, the ingredients (particularly the cement) shall preferably be used from a single source. When ingredients from different sources are used, the strength and other characteristics of the materials are likely to change and, therefore, they should only be used after proper evaluation and testing.

2.6.1.2 Portland Cement

Cement is any material that hardens and becomes strong adhesive after application in plastic form. Cement is the binding constituent of concrete. Similar types of cement from different sources and at different times from the same source exhibit variations in properties of concrete, especially in compressive strength. This variation in the strength of cement is related to the composition of raw materials as well as variations in the manufacturing process. The cement shall be tested initially once from each source of supply and, subsequently, at every two months interval. Adequate storage under cover is necessary for protection from moisture. Set cement with hard lumps is to be rejected.

2.6.1.3 Aggregates

In any concrete, aggregates (fine sand and Coarse) usually occupies about 70-75% and between 60 – 80% of the total volume of the concrete mass. The aggregates have to be graded so the whole mass of concrete acts as a relatively solid, homogeneous, dense combination with the smallest particles acting as inert filler for the voids that exist between the larger particles. This therefore suggests that the selection and proportioning of aggregates shall be given due attention as it not only affects the strength, but the durability and structural performance of the concrete also. Further, the aggregate is cheaper than cement and thus it is cheaper to use as much quantity of aggregate and as little of cement as possible. Aggregates provide better strength, stability and durability to the structure made out of cement concrete than cement paste alone. Aggregate is not truly inert because its physical, thermal and chemical properties influence the performance of concrete. While selecting aggregate for a particular concrete, the economy of the mixture, the strength of the hardened mass and durability of the structure must first be considered. Grading, maximum size, shape, and moisture content of the aggregate are the major source of variability. Aggregate shall be separately stock piled in single sizes. The graded aggregate should not be allowed to segregate.

2.6.1.4 Water

The water used for mixing concrete shall be free from silt, organic matter, alkali, and suspended impurities. Sulphates and chlorides in water should not exceed the permissible limits. Generally, water fit for drinking may be used for mixing concrete.

2.6.1.5 Personnel

The basic requirement for the success of any quality control plan is the availability of experienced, knowledgeable and trained personnel at all levels. The designer and the specification-writer should have the knowledge of construction operations as well. The site engineer shall be able to comprehend the specification stipulation. Everything in quality control cannot be codified or specified and much depends upon the attitude and orientation of people involved. In fact, quality must be a discipline imbibed in the mind and there shall be strong motivation to do everything right the first time.

2.6.1.6 Equipment

The equipment used for batching, mixing and vibration shall be of the right capacity. Weigh-batchers shall be frequently checked for their accuracy.

2.6.1.7 Workmanship

The activities involved in the workmanship in all stages of concreting, i.e. batching of materials, mixing, transportation, placing, compaction, curing and finally testing and inspection.

2.6.1.8 Ready Mixed Concrete

If instead of being batched and mixed on site, concrete is delivered for placing from a central plant, it is referred to as ready-mixed or pre-mixed concrete. This is used for large batches with lorry transporters up to 6m³ capacity. It has the advantage of eliminating site storage of materials and mixing plant, with the guarantee of concrete manufactured to quality-controlled standards. Placement is usually direct from the lorry therefore site-handling facilities must be co-ordinate with deliveries. Advantages of Ready-Mix Concrete:

- (a) Close quality control of batching which reduces the variability of the desired properties of the hardened concrete.
- (b) Use on congested sites or in highway construction where there is little space for a mixing plant and aggregate stockpiles.
- (c) Use of agitator trucks to ensure care in transportation, thus preventing segregation and maintaining workability
- (d) Convenience when small quantity of concrete or intermittent placing is required.

The disadvantage of ready-mix concrete is that it is costlier by about 10 – 15% than concrete mixed at project site. But this is often off-set by savings in site organization, in supervisory staff, and in cement content.

2.6.1.8 Concrete Mix Ratio

When making concrete it's important to use the correct concrete mixing ratios to produce a strong, durable concrete mix. Mixing water with the cement, sand, and stone will form a paste that will bind the materials together until the mix hardens. The strength properties of the concrete are inversely proportional to the water/cement ratio. Basically this means the more water you use

to mix the concrete (very fluid) the weaker the concrete mix. The less water you use to mix the concrete (somewhat dry but workable) the stronger the concrete mix. Accurate concrete mixing ratios can be achieved by measuring the dry materials using buckets or some other kind of measuring device. By measuring the mixing ratios you will have a consistent concrete mix throughout your entire project.

2.7 Palm Kernel Shell

Palm kernel shells (PKS) also known as Oil Palm Shells (OPS) are the by-product of palm oil and palm kernel oil production, and are fractions of shells that result from the cracking of the nuts. PKS is obtained as crushed pieces, the sizes of which vary from fine aggregates to coarse aggregates, after the crushing of palm kernel to remove the seed, which is used in the production of palm kernel oil (Olutoge, 2010). According to Alengaram, et al, (2010), Palm kernel shells (PKS) are organic waste materials obtained from crude palm oil producing factories in Asia and Africa. The Palm Oil Plant (*Elaeis Guinensis*), considering its three different varieties Dura, Pesipher and Tenera produces an edible fruit similar to an apricot which has a nut inside. Palm kernel shells are hard, flaky and of irregular shape (Oti and Kinuthia, 2015). There is no single type of shape that can be used to describe the palm kernel shell. The shape depends on the pattern of breaking during the nut cracking. It is usually composed of many shapes among which are roughly parabolic or semi-circular shapes, flaky shapes and other irregular shapes (Okafor, 1988). Palm kernel shell are hard in nature and do not deteriorate easily when used for concrete and therefore, do not contaminate or leach to produce toxic substances (Basri et al., 1999). Palm kernel shell may consist of about 65 to 70% of medium size particles in the range of 5 to 10 mm based on the method of cracking the nut (Alengaram et al., 2010).

Physical and mechanical properties of palm kernel shell make it suitable for so many applications. It can be used as an aggregate for concrete production (Okafor, 1988; Okpala, 1990; Osei and Jackson, 2012). Okoroigwe et al. (2014) used palm kernel shell as a sorbent material for industrial water treatment and stated that the physical and chemical properties of the material make it suitable for the purpose. Palm kernel shell can also be used in road construction. However, for heavily trafficked roads, palm kernel shell replacement for aggregate of stone dust and bitumen in 10% blend with asphalt is recommended (Ndoke, 2006). Palm kernel shell is also used in the preparation of pozzolana, a cement substitute material that has been developed by the

Kwame Nkrumah University of Science and Technology, Kumasi, Ghana (FAO Rome, 2002). Also, Oti and Kinuthia (2015) used palm kernel shell ash to produce concrete and stated that the potential to replace up to 50% Portland cement with palm kernel shell ash burnt at oven temperature of 750oC is more feasible. Also, a recent study has shown that palm kernel shell can be used as a partial replacement for sand in sandcrete block production. Blocks produced from palm kernel shell aggregates are denser and stronger than the traditional sandcrete blocks when the palm kernel shell aggregate content do not exceed 10% (Dadzie and Yankah, 2015).

2.8 Properties of Palm Kernel Shell (PKS)

Palm kernel shell has both physical and mechanical properties suitable for use as coarse aggregate in concrete. According to Okoroigwe et al. (2014), the material physical and chemical properties determined using standard methods showed that it can fill useful applications in light weight construction as material filler and as sorbent material for industrial water treatment. The shell has a 24 hours water absorption capacity range of 21 – 33% (Shafiqh et al., 2010). Okpala (1990) stated that the indirect compressive strength of PKS aggregate was 12.1 MPa with a standard deviation of about 2MPa. The material bulk density ranges from 572 to 620 kg/m³ (Itam et al., 2016; Okafor, 1988; Alengaram et al., 2010). The material has been found to have a specific gravity of 1.34 (Williams et al., 2014). Properties of PKS given by researchers summarized in Table 2.3, show that the material possesses desired characteristics that rendered it necessary to be used as coarse aggregate for concrete production.

Table 2.1: Properties of Palm Kernel Shell (PKS)

Author (Researchers)	Specific Gravity (Gs)	Bulk Density (kg/m³)	Shell Thickness (mm)	Water Absorption for 24 hr. (%)	Fineness Modulus	Aggregate Impact Value (%)
Okafor, 1988	1.37	589	-	27.3	-	6.0
Okpala, 1990	1.14	595	-	21.3	-	-
Alengaram et al., 2010	1.27	620	2.95	25.0	6.24	3.91

Shafigh et al., 2010	1.22	-	-	18.73	5.72	-
Itam et al., 2016	1.21	572	-	25.64	-	6.65

2.9 Palm Kernel Shell Concrete (PKSC)

Palm Kernel Shell concrete (PKSC) is a concrete produce by substituting coarse aggregate either partially or fully with PKS. Depending on the mix design, it can be classified as either Structural Light Weight Concrete (SLWC) or an Insulating Light Weight Concrete when the 28-day compressive strength is below 17N/mm². According to the American Concrete Institute (ACI), Structural Light Weight Concrete is defined as a concrete made with low density aggregate that has an air-dry density of not more than 1840 kg/m³ and a 28 day compressive strength of more than 17N/mm² (ACI 116R, 2000). BS 5328 (1997), defined SLWC as hardened concrete having an oven dried density not greater than 2000 kg/m³. Okafor (1988) suggested that the use PKS as a full replacement of coarse aggregate cannot produce concrete with compressive strength above 30N/mm² and that PKS is suitable for concrete grade 25 and below compared to conventional coarse aggregates. However, in latter researches, Alengaram et al. (2010) increased the 28-days compressive strength to 36-38N/mm² by incorporating silica fume while Shafigh et al. (2011) developed a new method to produce high strength PKS concrete of 28-days compressive strength of 53N/mm² by using crushed PKS. Osei and Jackson (2012), studied PKS as Coarse Aggregates in Concrete and ascertained the possibility to replace coarse aggregate up to 100 percent but recommended that batching by volume should be used for better results. The mechanical and structural properties of PKSC have been compared with normal weight concrete (NWC) by many researchers to show the effectiveness of PKSC (Alengaram et al., 2013).

2.10. Review of Effect of Palm Kernel Shell on Mechanical Properties of Light Weight Concrete.

2.10.1.1 Workability

The most important property of fresh concrete is its workability defined as the ease with which concrete is mixed, transported, placed, compacted, and finished without segregation. Slump test is a standard test for determining the workability of concrete. It is used to calculate the variation

in the uniformity of mix of a given proportion and also to measure the consistency of the concrete. Workability of PKSC is dependent on the water to cement ratio and also the content of PKS. As can be seen in Figure 2-2, Danashmand and Saadatian (2011) performed a slump test on PKSC for different percentages of PKS (Oil Palm Shell-OPS) content as a partial replacement for coarse aggregate with a constant water cement ratio of 0.5 and showed that with increase in PKS content, the workability of the concrete reduces.

There is a similar trends also being reported that the presence of palm kernel shell as aggregate can lead to better workability for a same water-cement ratio.(FO.,O.,1988).However as the percentage of the PKS (palm kernel shell) replacement increase, the slump of the concrete will decrease. This may due to the higher shells content combined with the irregular and angular shapes of the shells lead to poor workability. Lower workability might also due to the friction of the angular shapes between the shells and lower fines content. (Alengaram, U.J., J.M.Z., Mahmud H.). Besides, the porosity of the shells can influence the workability. The higher the porosity of the shells, the absorption capacity will be higher, which consequently reduces the workability. The lower compacting values of the shells indicate that less work is done on the shell concrete by gravity. This may due to the lower density of the shell aggregate when compared with granite aggregate.

Also, according to Alengaram et al. (2008), higher palm kernel shell content in the mix combined with the irregular and angular shapes of palm kernel shell result in poor workability. This poor workability might be due to the friction between the angular surfaces of palm kernel shell particles and lower fine content. A reduction in palm kernel shell content and a subsequent increase in fine aggregate content increases workability as can be seen from reports by different researchers summarized in Table 2.2..

Table 2.2: Slump of Palm Kernel Shell Concrete (PKSC) by researchers for different mixes.

Author (Researchers)	w/c	Mix Proportion	Slump (mm)
Abdullah 1984	0.6	1:1.5:0.5	200
	0.4	1:2:0.6	260

Okafor 1988	0.48	1:1.7:2.08	8
	0.65	1:2.1:1.12	50
Okpala 1990	0.5	1:1:2	30
	0.6	1:1:2	63
	0.7	1:1:2	Collapse
	0.5	1:2:4	3
	0.6	1:2:4	28
	0.7	1:2:4	55
Mahmud et al. 2009	0.35	1:1:0.8	160

2.10.1.2 Density

For structural applications of Light Weight Concrete (LWC), the density is often more important than the strength (Rossignolo et al., 2003). The density of concrete is study in terms of bulk density, fresh density, and dry density. According to Okafor (1988), the fresh density of PKSC is in the range of 1753 – 1763 kg/m³ depending on the mix proportion, water to cement ratio, and also the use of sand. Mannan and Ganapathy (2001), based on the mix proportion also reported the fresh density of PKSC in the range of 1910 – 1958 kg/m³. Alengaram et al., 2008, reported the fresh density of PKSC to be approximately 1880 kg/m³ by incorporating 10% silica fume and 5% fly ash by weight with a cement : sand : aggregate : water ratio of 1:1.2:0.8:0.35. Usually the fresh density of PKSC is about 100 – 120 kg/m³ lower than the saturated density of light weight concrete (Alengaram et al., 2013). Osei and Jackson (2015) showed that the dried density of PKSC reduces with an increase in PKS content but increases with curing time.

2.10.1.3 Water Absorption Capacity

According to Basheer et al. (2001), water absorption is the transport of liquids in porous solids caused by surface tension acting in the capillaries. Water absorption for LWC such as expanded polystyrene concrete and pumice aggregate concrete is in the range of 3 – 6% according to Babu and Babu (2003), and 14 – 22% according to Guduz and Ugur (2005) respectively. For PKSC, Teo et al. (2007) showed that the water absorption is 11.23% and 10.64% for air dry curing and full water curing respectively. This high water absorption for palm kernel shell concrete (PKSC)

can be explained by the analysis of palm kernel shell structure. Alengaram et al. (2011) examined the structure of palm kernel shell using a scanning electron microscope and it was observed that tiny pores in the range of 16 - 24 μ m exist on the convex surface of palm kernel shell (PKS) which are responsible for the high water absorption of palm kernel shell concrete (PKSC).

2.10.1.4 Creep

A load equivalent to a stress of 6.0 N/mm² are applied on three 150 mm diameter cylinders made from lightweight concrete with palm kernel shell as aggregates in order to perform the creep test according to ASTM. The strain obtained by deducting the initial reading from the final reading immediately after loading. The readings were taken after six hours, then daily for one week, weekly for one month and monthly for nine months. Strain readings of the control sample were taken at the same time schedule. The total strains then divided by the average stress giving the total strain per unit stress. This total strain per unit stress then plotted. The results show that the creep curve for the lightweight concrete with palm oil shells shows a large creep compared with the ordinary 18 concrete. The creep rate for lightweight concrete using palm oil shells did not show a constant value after 3 months, and this property will be concerned when used as structural lightweight concrete.

2.10.1.5 Drying Shrinkage

Generally, all the cement products undergo volume changes which are small in values with response to the changes in moisture conditions. Although the volume changes are small, but the effects are considerably important. When a fresh concrete dried, it undergoes shrinkage which is termed as initial drying shrinkage. After that, the concrete will subsequently experience the alternative wetting and drying showing the alternative expansion and contraction which termed as reversible moisture movement. The reversible moisture expansion in lightweight concrete with response to the change in moisture condition is found that more often than but not as great as the initial drying shrinkage. Recent study shows that not only the cement undergo the shrinkage, but a few natural aggregate have shown marked shrinkage that contribute the total shrinkage of the concrete. (Andrew, 1962).

The shrinkage of concrete is about 50% greater than the normal weight concrete. Besides, concrete with the aggregate having opened textured and irregular surface can produce shrinkage of about 1000 micro strain. (Short, 1978). Tensile stress can be set up in the concrete as the result of drying shrinkage, especially it is restrained. If the shrinkage stress exceeds the tensile strength of the concrete, crack will occurred. (Andrew, 1962). Study was conducted by researchers to study the drying shrinkage of the kernel shell concrete. It was found that the kernel shell concrete experienced more shrinkage of about 14% higher than the normal weight concrete. Shrinkage can be due to the loss of free water in concrete mixture, the settlement of solids, drying of concrete and chemical reaction of the cement paste. (Mannan, 2002). This drying shrinkage is a long lasting process when the concrete exposed to dry condition, same as the hydration process. There are some factors which govern the drying shrinkage of the lightweight concrete such as the water-cement ratio, curing temperature, moisture content, admixture, aggregate characteristic (with the stiffness, content and volume/surface ratio), relative humidity, and the rate and duration of drying. (Mindess, 1981).

2.10.1.6 Compressive Strength

Compressive strength is the most commonly used parameter to describe the quality of concrete in practice (Weigrink et al., 1996). All other mechanical parameters such as flexural strength, splitting tensile strength and modulus of elasticity directly depend on the compressive strength of the concrete (Alengaram et al., 2013). Ikponmwosa et al., (2014), Daneshmand and Saadatian (2011), and Olutoge et al. (2012), all reported that the compressive strength of PKSC is dependent on the amount of PKS aggregate in the concrete and that the strength increases with curing age.

Depending on the mix design, percentage of palm kernel shell (PKS) aggregate, and method of curing, different grades of PKSC have been reported by researchers. Table 2.3 shows the compressive strength of palm kernel shell concrete (PKSC) by various researchers. Okpala (1990) reported a 28 – day compressive strength of 22.2 MPa using a water to cement ratio of 0.5 and a mix design of 1: 1: 2 (cement: sand: aggregate). Shafigh et al. (2011), incorporated steel fibers using a water to cement ratio of 0.38 and a design mix of 1: 1.736: 0.72 (cement: sand: aggregate) and reported a 28 – day compressive strength in a range of 39.34 – 44.95MPa.

Table 2.3: Compressive Strength of Palm Kernel Shell Concrete (PKSC).

Author (Researchers)	Water/Cement ratio	Mix Proportion	Compressive Strength at 28 days (MPa)
Okafor, 1988	0.48	1 : 1.7 : 2.08	23
Okpala, 1990	0.5	1 : 1 : 2	22.2
Alengaram et al., 2010	0.35	1 : 1.2 : 0.8	37.41
Shafigh et al., 2011	0.38	1 : 1.736 : 0.72 (steel fibers)	39.34 – 44.95

In other to build on some of the gaps identified from previous researches conducted and to comprehensively study the effect of partial replacement of coarse aggregate with palm kernel shell, the coarse aggregate employed for this research will be admixed with palm kernel shell in a stepped increase of 10% starting from 0% (control) to 50% by weight of coarse aggregate so as to establish six different specimen.

2.11 Suitability of Palm Kernel Shell Concrete (PKSC).

PKS has been experimented in research as light weight aggregate to produce light weight and low cost concrete since 1984 (Alengaram et al., 2013). According to Shafigh et al. (2010), research over the last two decades has shown that palm kernel shell (PKS) can be used as a lightweight aggregate for producing low cost and structural lightweight concrete. Also, it has been reported by Yap et al. (2013), that palm kernel shell (PKS) is a suitable replacement for coarse aggregate to produce high strength light weight concrete with 28 days compressive strength up to 53MPa.

Okafor (1988) tested the physical properties of the shell, the compressive, flexural, and tensile splitting strength of the PKS concrete. Three mixes of widely different water to cement ratio

were used with 100% coarse aggregate replacement with palm kernel shell (PKS). The properties tested were compared with those of similar concrete specimens made with crushed granite as coarse aggregate. The results showed that the material is suitable to produce concrete grade 25 and below. Similarly, Williams et al. (2014), produced a concrete with 100% replacement of coarse aggregate using PKS at a mix design of 1:2:4 (cement: sand: coarse aggregate) and a water to cement ratio of 0.65. The results showed that the compressive and flexural strength improved with age of curing, though the compressive and flexural strength of palm kernel shell concrete (PKSC) were low as compared to that of the normal weight concrete (NWC). They concluded that palm kernel shell can be used for concrete production as lightweight aggregate and therefore can be used to produce light weight concrete. The properties of palm kernel shell fresh concrete are however excellent, very workable, consistent and easily placed. Therefore, with the above information, it can be seen that the palm kernel shell is suitable for the production of low structural concrete (light weight concrete) by replacing coarse aggregate

2.12 Research Gaps

Increase in human population in Nigeria has led to rapid development in construction activities particularly to meet human need for shelter, mobility and other needs. Construction of some of the identified human needs (building, shelter) requires the use of concrete. Recently, the cost of coarse aggregate used for production has risen significantly. These costs of coarse aggregate along with their scarcity have pushed researchers to find alternatives for those conventional ones. (Alengaram et al., 2013; Yap et al., 2013; Williams et al., 2014 and Itam et al., 2016), used palm kernel shell as a replacement for coarse aggregate to produce light weight concrete leading to a significant reduction in the cost of concrete. Hence to further contribute towards low cost construction and environmental protection, production of concrete from partial replacement of coarse aggregate with palm kernel shell will significantly reduce construction cost. However, limited information is available on the effect of palm kernel shell as partial replacements for coarse aggregate on the properties of light weight concrete. Therefore, investigating the effect of palm kernel shell on mechanical properties of light weight concrete becomes necessary. Hence, this research will evaluate the effect of partial replacement of coarse aggregate with palm kernel shell on mechanical properties of light weight concrete.

CHAPTER THREE

MATERIALS AND METHODS

This section presents the material and methods used to actualize the research goal. Relevant standards were employed to ascertain how the materials collected be analyzed and also the various laboratory tests to be conducted. All Tests such as sieve analysis test for fine, coarse aggregate, specific gravity of fine and coarse aggregate, water Absorption of the fresh concrete, slump or workability test of fresh concrete and compressive strength of hardened concrete were carried out at Civil Engineering Laboratory Nnamdi Azikiwe University Awka Anambra State.

3.1 Collection and Preparation of Materials

3.1.1 Water

Water sample used for the experimental study was collected within the school environment. The water sample passed all the necessary requirement for use as ingredient of concrete based on the fact that it is colourless, devoid of suspended solid particles, contains infinitesimal trace of dissolved solid particles with no trace of turbidity after being subjected to laboratory testing. The water was collected in two gallons

3.1.2 Fine Aggregate (Sand)

Sand sample used in producing the concrete was provided at a construction site at Nnamdi Azikiwe University Campus. The sand was Sieved through 5.0mm test sieve to remove larger particles and then air-dried to a saturated state of an aggregate. The sample passed the necessary requirement for use as ingredient of concrete based on the fact that it is gritty with particle sizes visible to the naked eyes, physical properties of the sand samples were determined prior to its incorporation into the concrete. Index properties of the sand sample were determined prior to its incorporation into the concrete.

3.1.3 Coarse Aggregate

Granite samples designated as GT was procured from Infrastructure Development Company (popularly known as IDC) located along Enugu-Onitsha express way. After procurement, the granite samples were conveyed to the laboratory unit of Department of Civil Engineering Nnamdi Azikiwe University Awka Anambra State where the index properties of the aggregate were determined. The granite sample passed all the necessary physical test in that, it has high crushing strength, it is relatively large in size (within range of 4.75mm to 20mm) and is a representative of granite (chippings) in color. The granite sample will be partially admixed with palm kernel shell in a stepped increase of 5% by weight of coarse aggregate.

3.1.4 Cement

Ordinary Portland cement (Dangote cement) was used for the experimental study. This cement is designated as OPC. The cement was purchased at Onitsha Market in Anambra State. Upon purchase, the cement was conveyed to school laboratory where it was kept in a cool dry place preparatory for various laboratory testing. The cement sample satisfy the requirement for use as one of the major component of concrete in that, it was not caked or baked through visual inspection and quick setting time.

3.1.5 Palm Kernel Shell

The palm kernel shell designated as PKS was obtained from a palm kernel plantation at Enugu-Agidi in Anambra State Nigeria. The palm kernel shell sizes ranges between 5mm to 14mm. The shells were flushed with hot water containing detergent to remove dust and other impurities that could be detrimental to concrete. It was collected in two empty cement bags and was conveyed to laboratory, but before use, they were sun-dried and packed in plastic sheets to prevent contact with water, after sun-drying, the shell were taken to a crushing site where it was crushed into finer particles. The palm kernel shell will be used to partially replace coarse aggregate (granite) in a stepped increase of 5% to 20% by dry weight of coarse aggregate.

3.2 Laboratory Investigation

This section presents the experimental procedure and laboratory tests that were adopted for the study. The tests conducted was conducted for all the constituents of concrete and this include: Sieve analysis test for fine, coarse aggregate and additive (palm kernel shell), specific gravity of

fine, coarse aggregate and additive (palm kernel shell), slump (workability) test of fresh concrete, water absorption and compressive strength of hardened concrete. The aforementioned tests were conducted at Civil Engineering Laboratory Nnamdi Azikiwe University Awka Anambra State Nigeria. Below is a detailed description of test procedures and apparatus.

3.2.1 Particle Size Distribution (Sieve Analysis) Test

Sieve analysis is a procedure used to assess the particle size distribution of a granular material (sand, gravel). The size distribution is often of critical importance to the behavior of the material during use. Sieve analysis can be performed on any type of non-organic or organic granular material including sand, crushed rock, clay, granite, feldspar and a wide range of manufactured powders, grains and seed down to minimum size depending on the exact method. The standard grain size analysis test determines the relative proportion of different grain sizes as they are distributed among certain size ranges.

The particle size distribution (PSD) or sieve analysis were performed for coarse aggregate (granite), fine aggregate (sand) and additive (palm kernel shell) in order to determine the grading of each material in accordance with BS 812-103 (1990).

For aggregate to be well graded the value of coefficient of uniformity (C_u) has to be greater than 4 and 6 for gravel and sand respectively, while the Coefficient of Curvature (C_c) should be in the range of 1 to 3.

The apparatus needed for this experiment is listed below:

1. Stack of sieves including pan and cover.
2. Mechanical sieve shaker.
3. Weighing balance
4. Hand brush
5. Mortar and pestle (Used for crushing if the sample is conglomerated or lumped)
6. Thermostatically controlled Oven (With temperature of about 80°C-110°C).
7. Masking tape for identification of sample.
8. Exercise book and pen for recording of result.

9. The calculation for attaining Coefficient of uniformity and Coefficient of curvature are outlined below.

$$\text{Percentage retained (\%)} = \frac{\text{mass of soil retained in the sieve (g)}}{\text{total mass of soil sample (g)}} \times 100$$

$$\text{Cumulative percentage retained} = \sum \text{Percentage retained (\%)}$$

$$\text{Cumulative Percentage Finer (\%)} = 100 - \text{Cumulative percentage retained.}$$

$$\text{Coefficient of Uniformity} = \frac{D_{60}}{D_{10}}$$

$$\text{Coefficient of Curvature} = \frac{(D_{30})^2}{D_{10} \times D_{60}}$$

Where

D₁₀= particle size such that 10% of the soil is finer than the size

D₃₀= particle size such that 30% of the soil is finer than the size.

D₆₀= particle size such that 60% of the soil is finer than the size.

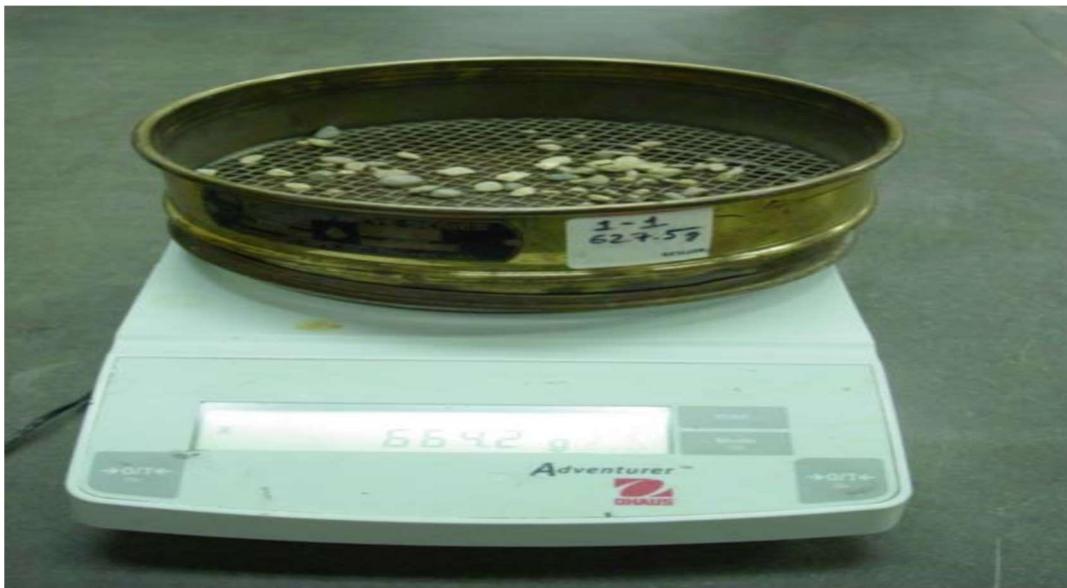


Plate 3.1 Apparatus for Particle Size Distribution Test (Sieve Analysis).



Plate 3.2 Apparatus for Particle Size Distribution Test (Sieve Analysis).

Test Procedure

Some procedures involve in sieve analysis test, after weighing the aggregate involves:

1. Arranging the stacks of sieve in the ascending order, placing in a mechanical sieve shaker, and thereafter pouring the sample and connecting the shaker for about 10-15 minute.
2. Disconnecting the sieve shaker and determine the mass retained on each of the sieve sizes.
3. Determine the percentage retained, Cumulative percentage retained and Cumulative percentage finer.
4. Plot the graph of sieve Cumulative percentage finer against sieve sizes.
5. Determine D10, D30 and D60 from the plotted graph.
6. Determine the Coefficient of Curvature and Coefficient of Uniformity and classify the soil using the American Association of State Highway and Transportation Official (AASHTO) and Unified Soil Classification System (USCS) respectively.

3.2.2 Specific Gravity of Fine Aggregate Test

Specific gravity is the ratio of mass of unit volume of soil at a stated temperature to mass of equal volume of gas-free distilled water at the same temperature (Krishna, 2002). Also as defined by (Braja, 2006), Specific gravity can be defined as the ratio of unit weight of a material to unit weight of water. The specific gravity of soil solids is often needed for various calculations in soil mechanics. It can be determined accurately in the soil laboratory.

The apparatus employed for this experiment includes:

1. Density bottle of 50ml capacity and a stopper.
2. Desiccator containing anhydrous silica gel.
3. Thermostatically controlled oven with temperature of about 80-110°C.
4. Weighing balance of 0.01g sensitivity.
5. Mantle heater.
6. Plastic wash bottle.
7. Distilled water.
8. Funnel
9. Thin glass rod for stirring.
10. 425um Sieve.
11. Dry piece of cloth for cleaning.
12. Masking tape for identification of sample.
13. Exercise book and pen for recording of result.

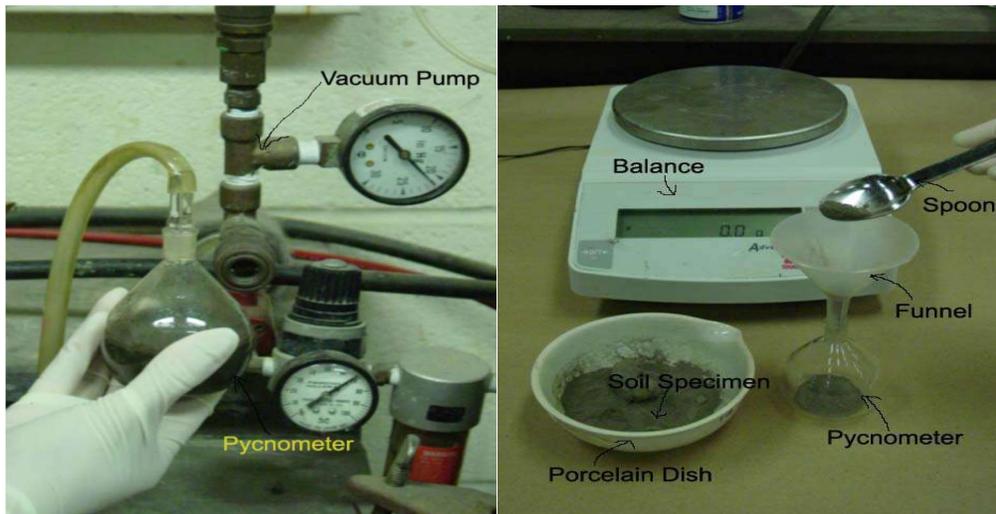


Plate 3.3 Apparatus used for Specific Gravity Test.

3.2.3 Specific Gravity of Coarse Aggregate Test

Specific gravity is the ratio of mass of unit volume of soil at a stated temperature to mass of equal volume of gas-free distilled water at the same temperature (Krishna, 2002). Also as defined by (Braja, 2006), Specific gravity can be defined as the ratio of unit weight of a material to unit weight of water. The specific gravity of soil solids is often needed for various calculations in soil mechanics. It can be determined accurately in the soil laboratory.

The apparatus employed for this experiment includes:

1. Wire Mesh Bucket
2. Container for filling water and suspending the wire Mesh in the water
3. Airtight container of capacity similar to wire Basket
4. A shallow tray
5. Two dry absorbent clothes.
6. Weighing Balance.
7. Distilled water.
8. Oven



Plate 3.4: Specific Gravity Test Kit for Coarse Aggregate

3.2.4 Slump (Workability Test)

Slump test is used to determine the workability or consistency of concrete mix prepared at the laboratory or the construction site during the progress of the work.

The procedures are as follows:

1. Clean the internal surface of the mold and apply oil.
2. Place the mold on a smooth horizontal non- porous base plate.
3. Fill the mold with the prepared concrete mix in 4 approximately equal layers.
4. Tamp each layer with 25 strokes of the rounded end of the tamping rod in a uniform manner over the cross section of the mold. For the subsequent layers, the tamping should penetrate into the underlying layer.
5. Remove the excess concrete and level the surface with a trowel.
6. Clean away the mortar or water leaked out between the mold and the base plate.
7. Raise the mold from the concrete immediately and slowly in vertical direction.

8. Measure the slump as the difference between the height of the mold and that of height point of the specimen being tested.

Calculation

Slump = Height of the slump cone – Height of the unsupported concrete.

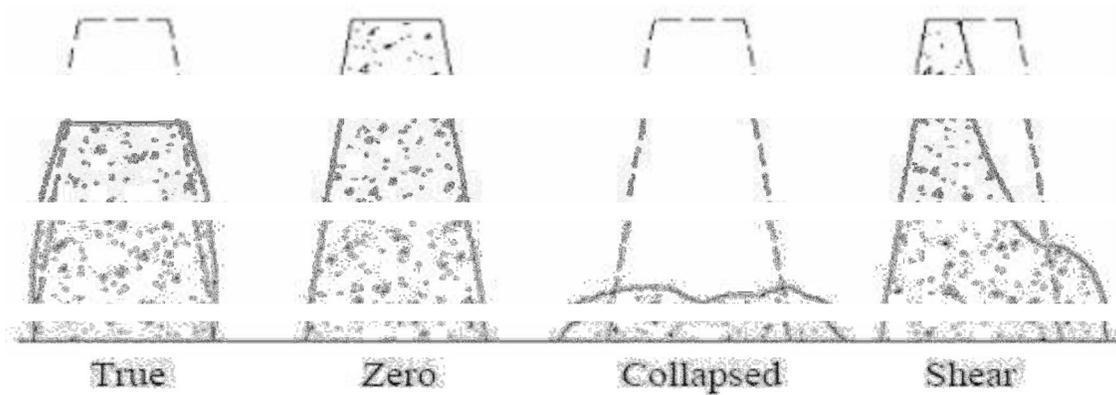


Figure 3.1: Types of Concrete Slump Test Results.

1. **True Slump** – True slump is the only slump that can be measured in the test. The measurement is taken between the top of the cone and the top of the concrete after the cone has been removed as shown above. In a true concrete just subsides shortly and more or less maintain the mould shape. This type of slump is most desirable and represents the reliable condition to get an idea about the workability of concrete.
2. **Zero Slump** – Zero slump is the indication of very low water-cement ratio, which results in dry mixes. This type of concrete is generally used for road construction. In this slump, the concrete maintains the actual shape of the mould as it is said to be stiff, consistent and almost non-workable.
3. **Collapsed Slump** – In the case, fresh concrete collapses completely. This is an indication that the water-cement ratio is too high, i.e. concrete mix is too wet or it is a high workability mix, for which a slump test is not appropriate.
4. **Shear Slump** – In this case, one-half of the cone slide down in an inclined plane, this slump indicates lack of cohesion in the concrete mix. Shear slump may occur in case of a harsh mix.



Plate 3.5: Apparatus used for Slump Test

3.2.5 Water Absorption Test

This is the rate at which a sample absorbs water. It is expressed in percentage. The oven-dried sample is weighted and then immersed in clean water for 24 hours.

Water absorption is expressed as $W_a = \frac{(W_w - W_d)}{W_d} * 100\%$

Apparatus

1. Weighing balance

2. Water bath
3. Drying cloth
4. Oven

Procedures

- 1 Place the sample cube in oven at 105 to 115°C for 18 to 24 hours
- 2 After removing from oven, measure the weight of the dry block
- 3 Place the block in water bath at 25 to 29°C for 24hours
- 4 After 24hours, dry the surface of the block with drying cloth
- 5 Measure the weight of the wet concrete cube

3.2.6 Compressive Strength of Hardened Concrete

The test method covers determination of compressive strength of cubic concrete specimens. It consists of applying a compressive axial load to molded cubes at a rate which is within a prescribed range until failure occurs.

The Apparatus Used includes:

1. **Testing Machine** - The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the rate specified in 5.5. The permissible error shall be not greater than ± 2 percent of the maximum load.
2. **Cube Moulds** - The mould shall be of 150 mm size conforming to IS: 10086-1982.
3. Weights and weighing device
4. Tools and containers for mixing,
5. Tamper (square in cross section)

Test Procedure

1. **Sampling of Materials** - Samples of aggregates for each batch of concrete shall be of the desired grading and shall be in an air-dried condition. The cement samples, on arrival at the

laboratory, shall be thoroughly mixed dry either by hand or in a suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material.

2. Proportioning - The proportions of the materials, including water, in concrete mixes used for determining the suitability of the materials available, shall be similar in all respects to those to be employed in the work.

3. Weighing - The quantities of cement, each size of aggregate, and water for each batch shall be determined by weight, to an accuracy of 0.1 percent of the total weight of the batch.

4. Mixing Concrete - The concrete shall be mixed by hand, or preferably, in a laboratory batch mixer, in such a manner as to avoid loss of water or other materials. Each batch of concrete shall be of such a size as to leave about 10 percent excess after moulding the desired number of test specimens.

5. Mould - Test specimens cubical in shape shall be 150mm × 150mm × 150mm .If the largest nominal size of the aggregate does not exceed 20mm, 100mm cubes may be used as an alternative. Cylindrical test specimens shall have a length equal to twice the diameter.

6. Compacting - The test specimens shall be made as soon as practicable after mixing, and in such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance.

7. Curing - The test specimens shall be stored in a place, free from vibration, in moist air of at least 90 percent relative humidity and at a temperature of $27^{\circ} \pm 2^{\circ} \text{C}$ for 24 hours $\pm \frac{1}{2}$ hour from the time of addition of water to the dry ingredients.

8. Placing the Specimen in the Testing Machine - The bearing surfaces of the testing machine shall be wiped clean and any loose sand or other material removed from the surfaces of the specimen which are to be in contact with the compression plates.

9. In the case of cubes, the specimen shall be placed in the machine in such a manner that the load shall be applied to opposite sides of the cubes as cast, that is, not to the top and bottom

10. The axis of the specimen shall be carefully aligned with the centre of thrust of the spherically seated platen. No packing shall be used between the faces of the test specimen and the steel platen of the testing machine.

11. The load shall be applied without shock and increased continuously at a rate of approximately 140 kg/sq cm/min until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained.

12. The maximum load applied to the specimen shall then be recorded and the appearance of the concrete and any unusual features in the type of failure shall be noted.

The compressive strength of concrete cube is computed as follows:

$$\text{Compressive Strength (N/mm}^2\text{)} = \frac{\text{Applied load (N)}}{\text{Area of Cube (mm}\times\text{mm)}}$$

Where applied load (N) = Force

Now conversion of applied load from Ton force to KN or N.

1 Ton force = 10kN or 10,000N.

For 220kN = 220 × 1000 = 220,000N (Assumed Load)

Area of cube = 150mm × 150mm = 22,500mm²

$$\text{Compressive Strength} = \frac{220,000\text{N}}{22,500\text{mm}^2} = 9.78\text{N/mm}^2 \text{ (Assumed Compressive Strength)}$$



Plate 3.6: Universal Testing Machine for Compressive Strength Test.

CHAPTER FOUR

RESULTS AND DISCUSSION

During the experimentation phase of the study, certain results were obtained which was useful in evaluating the effect of palm kernel shell on both wet and dry mechanical properties of concrete.

These results are presented below:

4.1 Results

The experimental results which will be valuable in assessing the effect of palm kernel shell on wet and dry mechanical properties of concrete includes the following:

- 1 Sieve Analysis Test Results
- 2 Specific Gravity Test Results
- 3 Slump (Workability) Test Results
- 4 Water Absorption Test Results
- 5 Compressive Strength Test Results

Below is a detailed description of the test results:

4.1.1 Sieve Analysis Test

Table 4.1: Sieve Analysis Test Result for Granite

Sieve Sizes	Mass Retained (g)	% Mass retained	Cum % Retained	Cum % finer
(mm)				
20	115.92	14.49	14.49	85.51
14	525.2	65.65	80.14	19.86
10	72.32	9.04	89.18	10.82
4.75	84.24	10.53	99.71	0.29
Tray	2.32	0.29	100.00	0.00
Total	800	100.00		

Table 4.2: Sieve Analysis Test Results for Sand

Sieve Sizes (mm)	Mass Retained (g)	% Mass retained	Cum % Retained	Cum % finer
4.75	1.21	0.40	0.4	99.60
2	7.83	2.61	3.01	96.99
1.18	15.44	5.15	8.16	91.84
0.6	225.21	75.07	83.23	16.77
0.3	40.99	13.66	96.89	3.11
0.15	8.04	2.68	99.57	0.43
0.075	0.62	0.21	99.78	0.22
Tray	0.66	0.22	100.00	0.00
Total	300.00	100.00		

Table 4.3: Sieve Analysis Test Results for Palm Kernel Shell

Sieve Sizes (mm)	Mass Retained (g)	% Mass Retained	Cum % Retained	Cum % finer
14	25	8.33	8.33	91.67
12.5	95	31.67	40	60.00
10	60	20.00	60	40.00
9.5	105	35.00	95	5.00
4.75	10	3.33	98.33	1.67
Tray	5	1.67	100.00	0.00
Total	300	100.00		

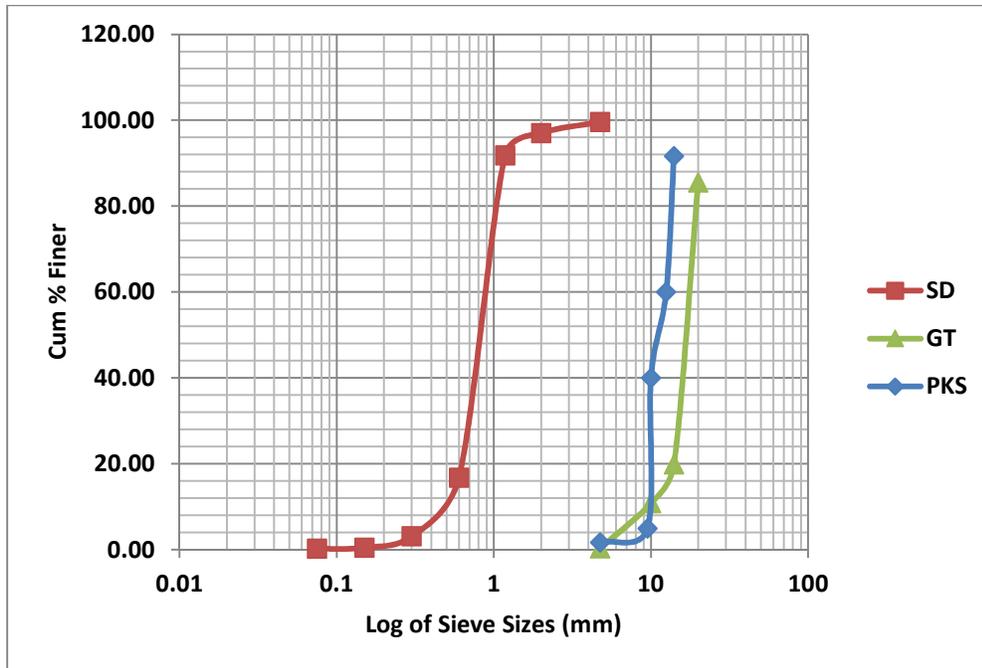


Figure 4.1: Particle Size Distribution Curve for Sand, Granite and Palm Kernel Shell

Figure 4.1 is the semi logarithmic plot of the particle size distribution of the GT, SD and PKS. Result recorded shows that for GT, the percentage passing through 4.75mm is 0.29 and according to AASHTO, it is classified as A-1-b and the constituent material constitutes an excellent sub-grade material. According to USCS, it is classified as GM (Gravel mixed with clay). The percentage passing through sieve size 0.075mm and 4.75mm for SD are 99.6 and 0.0033 respectively and according to AASHTO Classification system, it is classified as A-2-4 and SC (clayey sand) according to USCS Classification system. This material constitutes a good sub-grade material for road construction. While the percentage passing sieve size 4.75mm for the additive (PKS) is 1.67 and according to AASHTO, it is categorized as A-1-b and GM (gravel mixed with silt). The gradation of GT, SD and PKS obtained from their respective shape parameters ($C_u=1.35, 1.1, 0.85$ and $C_c=1.9, 1.8, 1.4$) shows that they are poorly graded.

4.1.2 Specific Gravity Test

Table 4.4: Specific Gravity Result for Sand

Determinants	Trial 1	Trial 2	Trial 3
Wt of density bottle, W₁ (g).	24.76	25.64	25.90
Wt of bottle + dry soil, W₂ (g).	34.74	35.63	35.90
Wt of bottle + soil + water, W₃ (g).	84.33	85.15	85.79
Wt of bottle + water, W₄ (g).	78.07	78.94	79.56

Table 4.5: Specific Gravity Result for Crushed Granite

Determinants	Trial 1	Trial 2	Trial 3
Wt of empty can	190.48	183.59	184.35
Wt of can + saturated aggregate	458.72	495.7	508.8
Wt of Saturated aggregate in air W₃ (g).	438.62	442.24	440.82
Wt of Oven-dried aggregate in air W₄ (g).	432.80	434.28	434.86

Table 4.6: Specific Gravity Result for PKS

Determinants	Trial 1	Trial 2	Trial 3
Wt of Saturated aggregate and can in water W_1 (g).	342.7	311.60	290.47
Wt of can in Water W_2 (g).	152.20	145.61	137.01
Wt of Saturated aggregate in air W_3 (g).	367.88	342.11	315.76
Wt of Oven-dried aggregate in air W_4 (g).	320.77	298.24	279.17

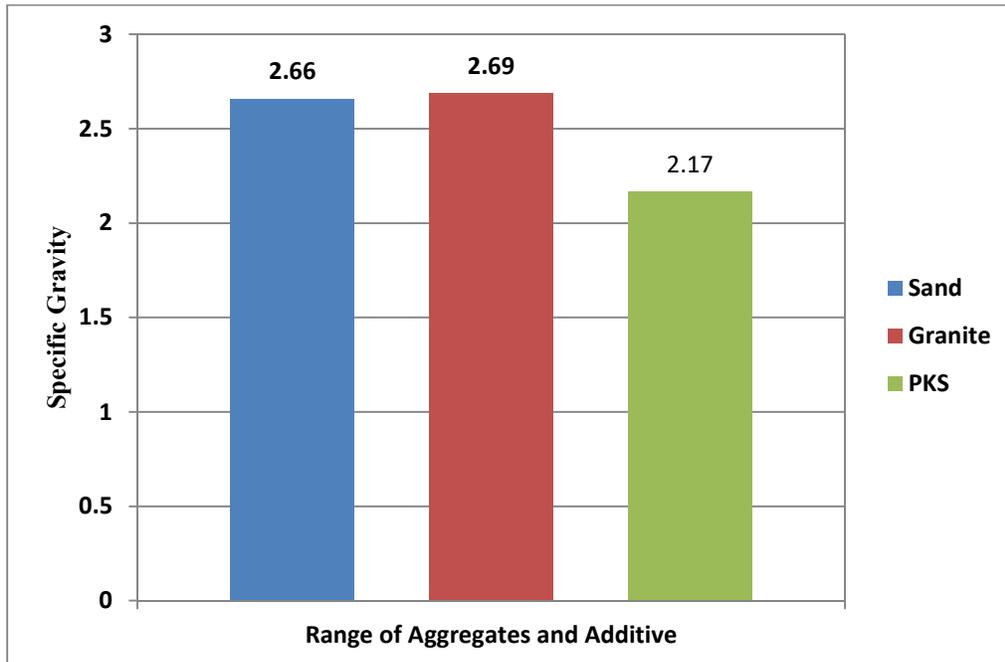


Figure 4.2: Specific Gravity Values of Aggregate and Additives

The specific gravity is defined as the ratio of weight of a sample to the rate of equal volume of water; it is used to obtain the unit weight of materials in the presence of water. Specific gravity test were conducted in accordance to ASTM D854-14 specification. For the sample designated as SD and GT and the additive (palm kernel shell) designated as PKS, the average apparent specific gravity computed are 2.66, 2.69 and 2.17 respectively. The range of specific gravity from 2.17 to 2.69 satisfies ASTM D854-14 requirement which states that the specific gravity of aggregates should be between 2.55 to 2.9 and therefore justifies the use of the aggregates for this work.

4.1.3 Slump Test

Table 4.7: Slump Test Results at Varying Percentages of PKS

Percentages of PKS	Height of Cone (mm)	Height of Collapse (mm)	Slump (mm)	Type of Slump Formed
0	300	265	35	True slump
5	300	270	30	True slump
10	300	278	22	True slump
15	300	284	16	True slump
20	300	292	8	True slump

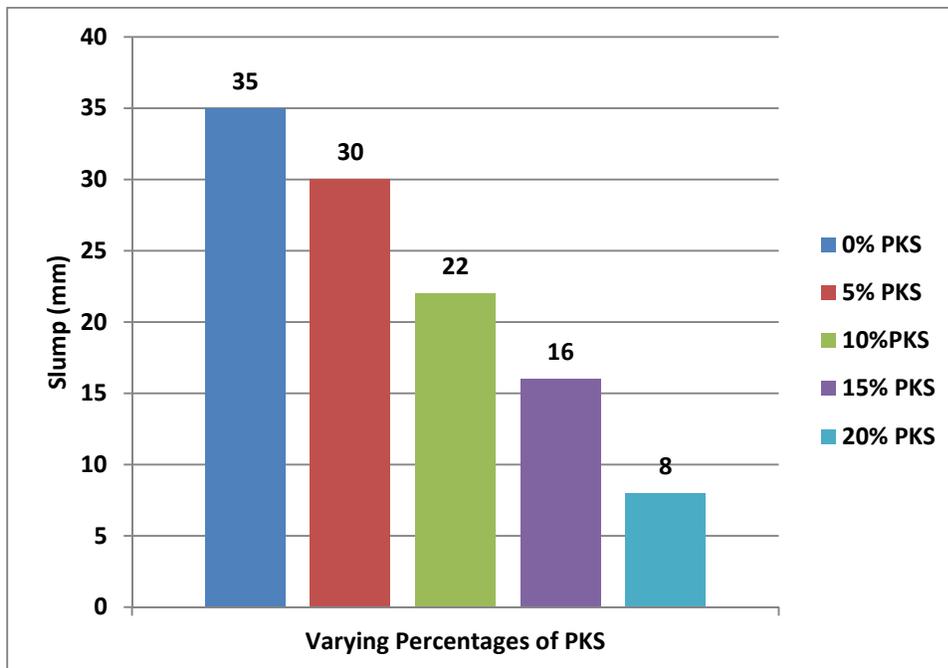


Figure 4.3: Slump Value of the Concrete at Varying Percentages of PKS

Table 4.7 shows the slump test result of the fresh concrete obtained at different percentages of palm kernel shell. The slump of the control specimen was generally higher than that of palm kernel shell concrete. On consistent addition of palm kernel shell to the concrete, it was observed that the slump of the concrete decreased. The decline in slump could be ascribed to the high water absorption of palm kernel shell. It can therefore be adjudged that concrete produced with palm kernel shell will require high amount of water to become workable. Evaluation of the slump type formed for both the plain (control specimen) and palm kernel shell concrete suggests that the slump type formed were true slump since the slump value did not exceed 40mm.

4.1.4 Water Absorption Test

Table 4.8: Water Absorption Test Results at Varying Percentages of PKS

Percentages of PKS (%)	Water Absorption (%)
0 (control)	1.10
5	3.10
10	4.36
15	6.09
20	5.84

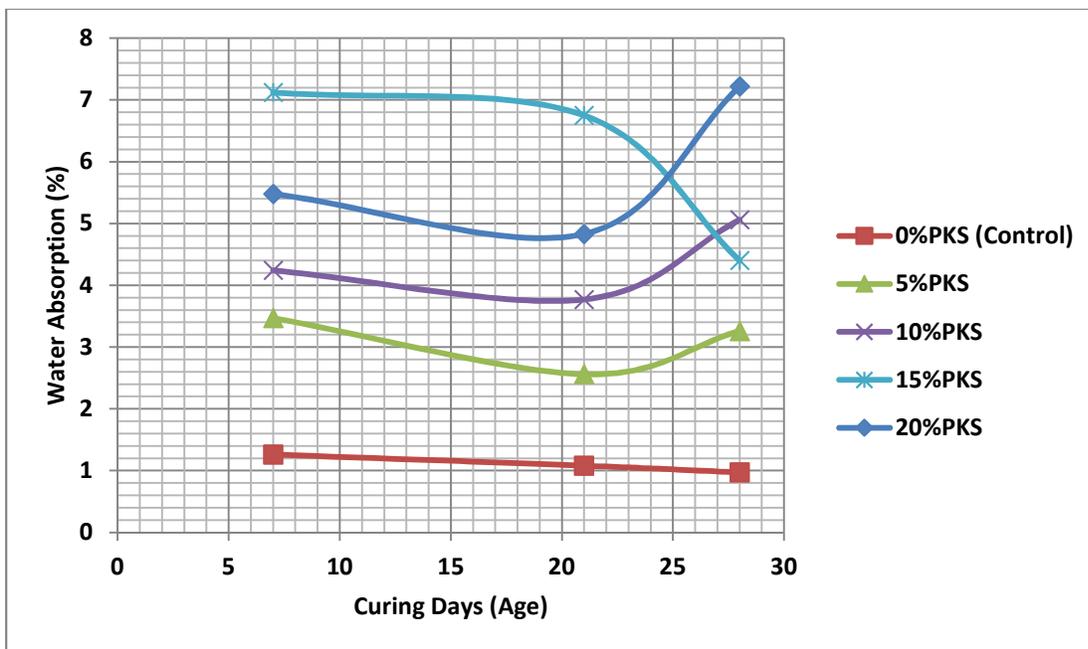


Figure 4.4: Graph Showing the Water Absorption of the Concrete at Intervals of Curing Days

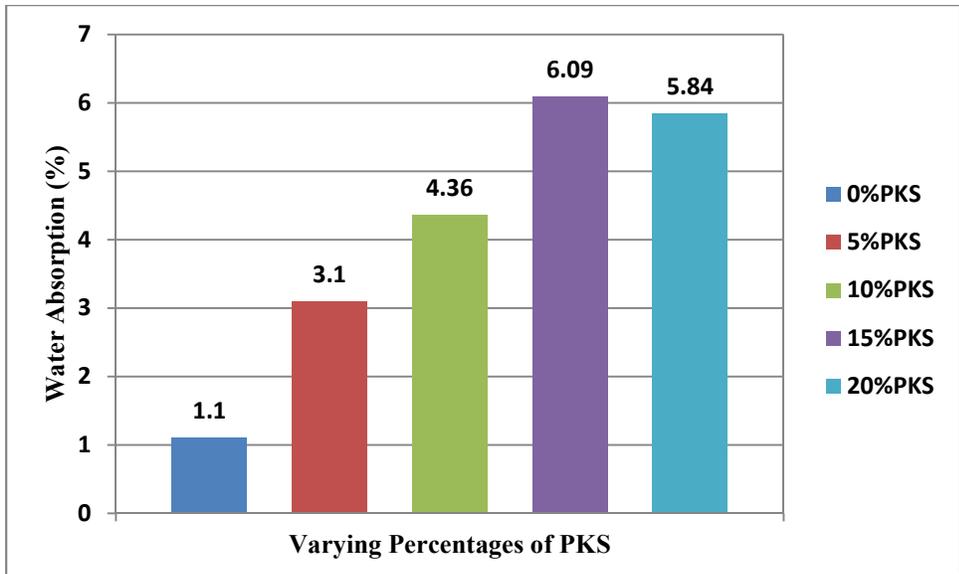


Figure 4.5: Chart Showing the Water Absorption of the Concrete at Varying Percentages of PKS

The water absorption test is one of the parameter used for assessment of the wet properties of the concrete. The water absorption of the control specimen was lower than that of palm kernel shell concrete. On addition of palm kernel shell from 5% to 20%, it was observed that the water absorption of the concrete increased although, a slight deviation was recorded at 20% palm kernel shell content which could be attributed to defective experimental process. The increase in water absorption of palm kernel shell concrete could be attributed to the internal structure of palm kernel shell. Palm kernel shell has porous nature and as results, requires high amount of water. The high water demand of palm kernel shell concrete makes the concrete unsuitable for civil engineering application.

4.1.5 Hardened Concrete Density

Table 4.9: Hardened Density Test Results at intervals of Curing Days

Curing Days (Age)	Dry Density (kg/m ³)
7	1823
21	1915
28	2048

Table 4.10: Hardened Density Test Results at Varying Percentages of PKS

Percentages of PKS (%)	Hardened Density (kg/m ³)
0 (control)	2282
5	2004
10	1850
15	1763
20	1630

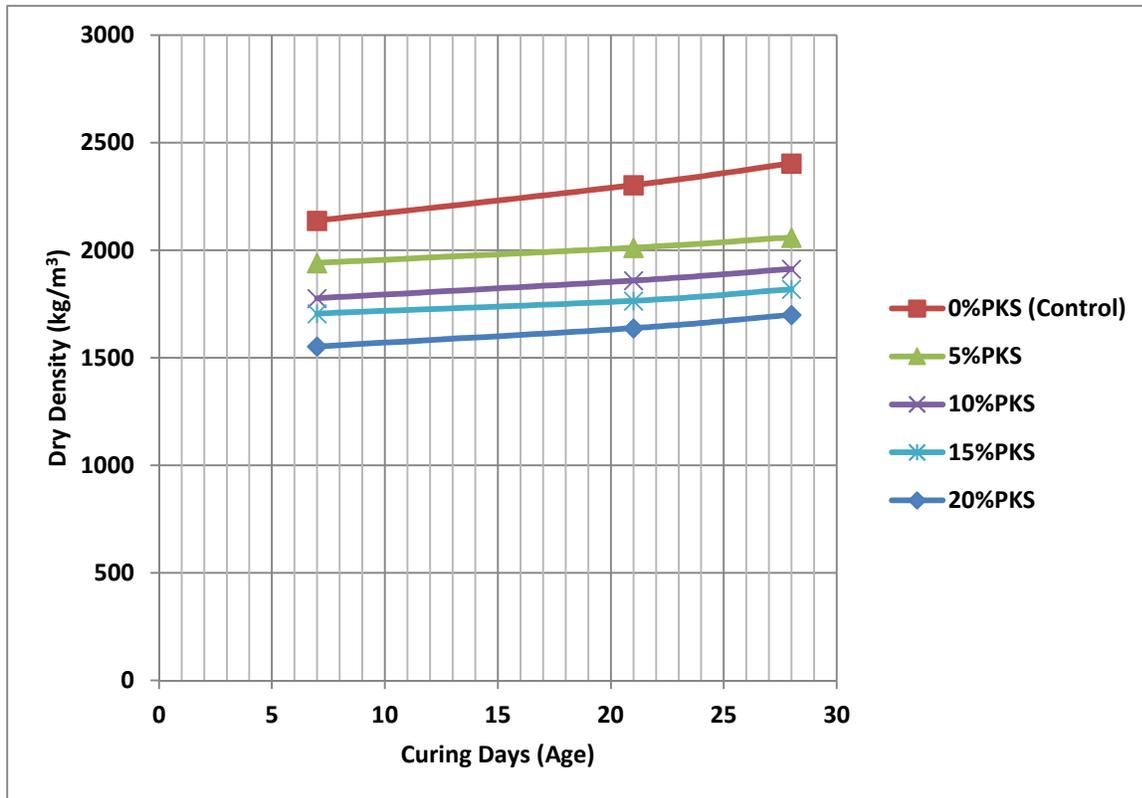


Figure 4.6: Graph Showing the Dry Density of the Concrete at Intervals of Curing Days

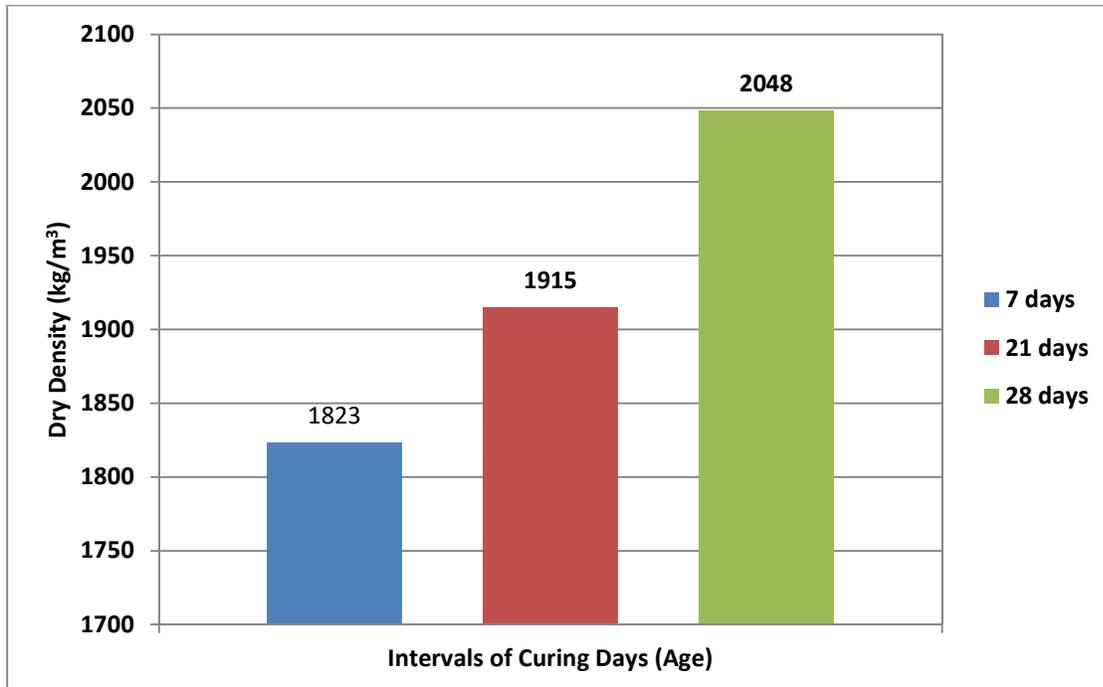


Figure 4.7: Graph of Hardened Density against Intervals of Curing Days

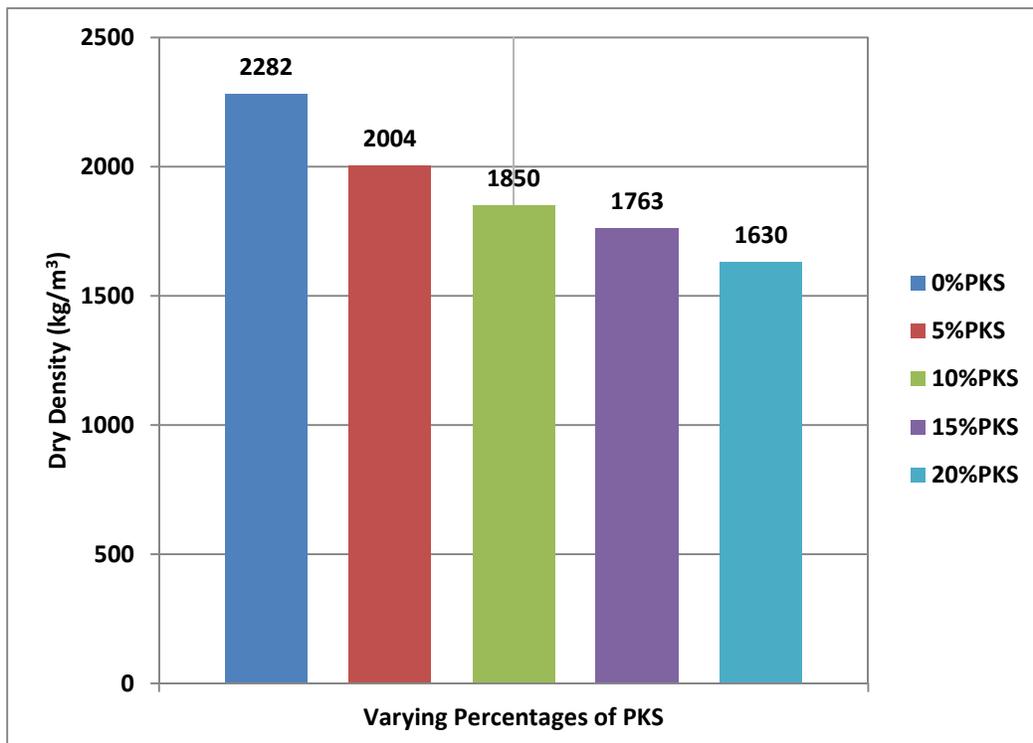


Figure 4.8: Graph of Dry Density against Percentage Replacement of PKS

Figure 4.6-4.8 shows the relationship between the hardened density of both the plain and palm kernel shell concrete against interval of curing days and percentage replacement of palm kernel shell. It was observed that the hardened density of both the control specimen and palm kernel shell concrete increased with curing days. The optimum value of the hardened density was attained at 0%PKS (control specimen). It was also observed that the density of the concrete decreased on consistent addition of palm kernel shell to the concrete..

4.1.6 Compressive Strength Test

Table 4.11: Compressive Strength Test Results at intervals of Curing Days

Curing Days (Age)	Compressive Strength (N/mm²)
7	16.63
21	17.62
28	18.23

Table 4.12: Compressive Strength Test Results at Varying Percentages of PKS

Percentages of PKS (%)	Compressive Strength (N/mm²)
0 (control)	23.57
5	18.20
10	17.07
15	14.76
20	13.96

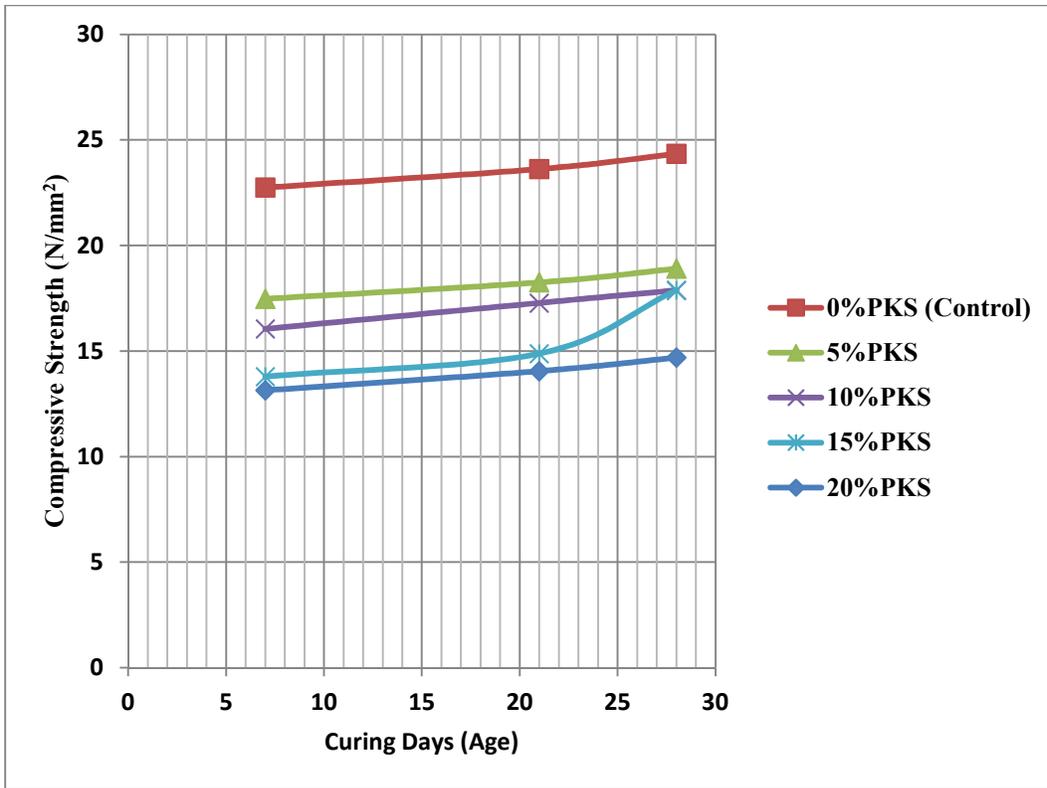


Figure 4.9: Graph of Compressive Strength against Intervals of Curing Days

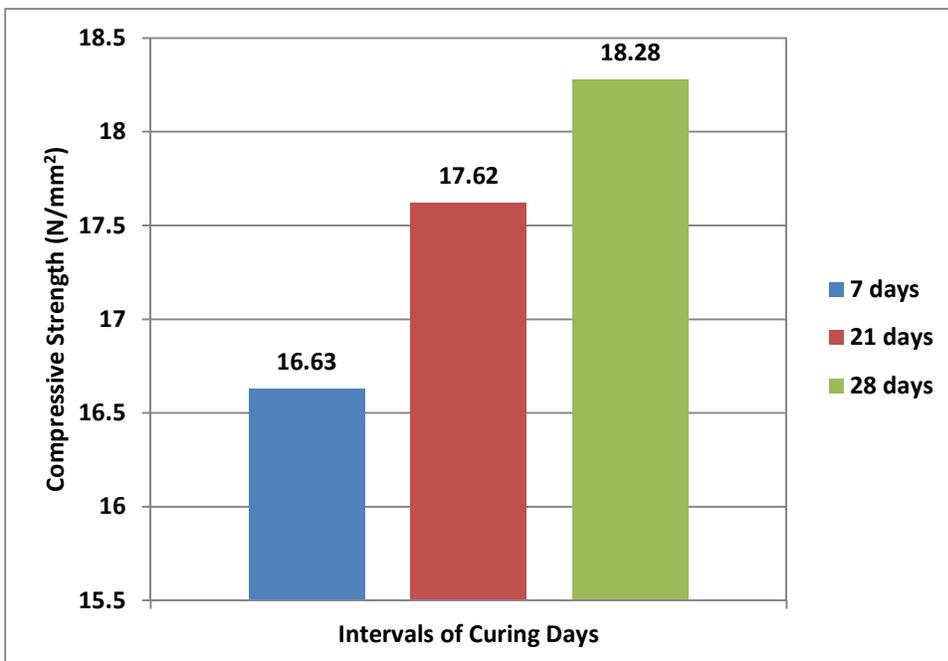


Figure 4.10: Chart Showing the Compressive Strength of the Concrete against Intervals of Curing Days

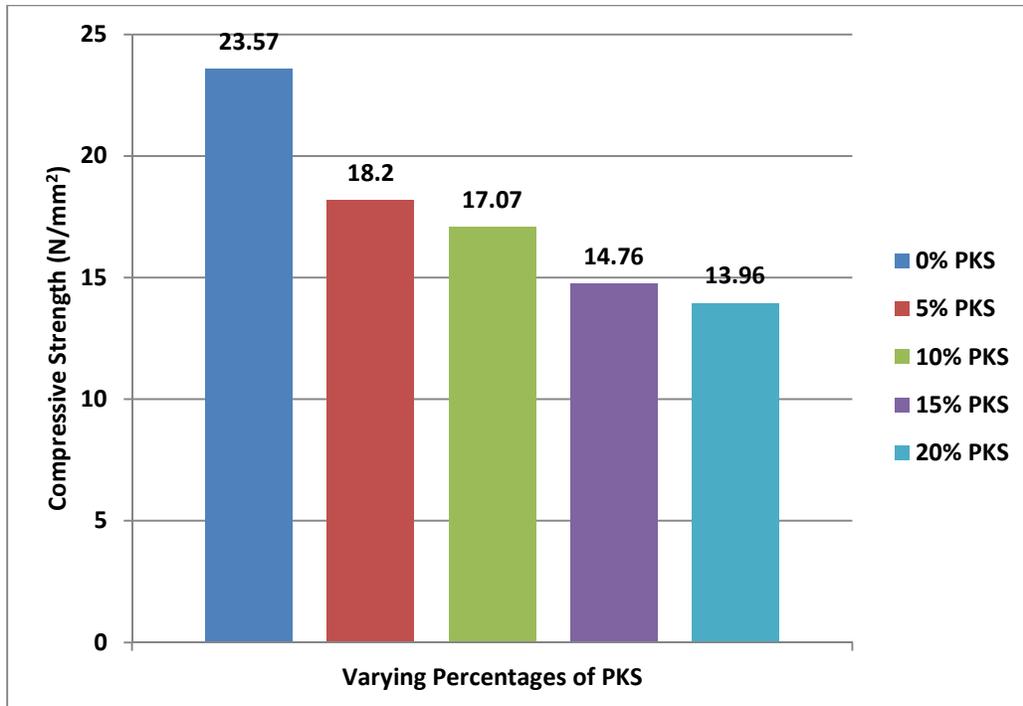


Figure 4.11: Graph of Compressive Strength against Percentage Replacement of PKS

Table 4.12 depicts the results obtained from compressive strength test of the hardened plain and palm kernel shell concrete at varying percentages of palm kernel shell and curing days ranging from 7-21-28 days. From the findings obtained, it was observed that the compressive strength of both the plain and palm kernel shell concrete increased with curing days. The compressive strength of the control specimen was relatively higher than the palm kernel shell concrete. On consistent addition of palm kernel shell to the concrete, it was observed that the compressive strength of the hardened palm kernel shell concrete decreased. The consistent decline in compressive strength could be attributed to the low density and high water absorption of palm kernel shell. Works indicative of these findings are the works of Oyejobi, et al. (2019), Gupta, et al. (2017) and Azuna, (2019).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the findings obtained on the production of light weight concrete with partial replacement of coarse aggregates with palm kernel shell, the following conclusion can be made:

1. Preliminary investigation of the index properties of the fine, coarse aggregates and additive (palm kernel shell) showed that all the concrete components satisfied the requirement for use as constituents for concrete production.
2. The slump of the concrete was found to decrease on consistent addition of palm kernel shell to the concrete.
3. The water absorption of the concrete was found to increase on consistent addition of palm kernel shell to the concrete.
4. The wet and dry density of the concrete was found to increase with curing days but decreased with increase in percentages of palm kernel shell.
5. The compressive of the hardened concrete was found to increase with curing days but decreased with increase in percentages of palm kernel shell.
6. The palm kernel shell was adjudged as feasible but ineffective modifier since no improvement in strength properties of the concrete was observed.

5.2 Recommendation

The following recommendations in the light of the findings obtained in the study can be drawn:

1. Concrete produced with palm kernel shell are light weight and can be suitable for structural and nonstructural purposes.
2. Concrete with 5%, 10%, and 15%, partially replaced with palm kernel shell can be used for structural purposes.
3. The concrete with 20% replacement should be subjected to further studies to ascertain the type of material to be used in other to enhance the concrete compressive strength and density with the primary consideration of reducing concrete production cost.

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APPENDIX A

Compressive Strength Test

Table A1: Compressive Strength Test Result for 0%PKS (Control)

Curing Days (Age)	Mix by Volume	Failure Load (kN)	Compressive Strength (N/mm²)	Average Compressive Strength (N/mm²)
7 days	1: 2: 4	515.8	22.92	22.74
		510.2	22.68	
		508.7	22.61	
21 days	1: 2: 4	528.6	23.49	23.62
		530.4	23.57	
		535.8	23.81	
28 days	1: 2: 4	544.5	24.20	24.34
		548.2	24.36	
		550.3	24.46	

Table A2: Compressive Strength Test Result for 5%PKS

Curing Days (Age)	Mix by Volume	Failure Load (kN)	Compressive Strength (N/mm²)	Average Compressive Strength (N/mm²)
7 days	1: 2: 4	404.3	17.97	17.47
		394.6	17.54	
		380.5	16.91	
21 days	1: 2: 4	410.5	18.24	18.25
		418.6	18.60	
		402.8	17.90	
28 days	1: 2: 4	428.3	19.04	18.90
		420.5	18.69	
		426.8	18.97	

Table A3: Compressive Strength Test Result for 10%PKS

Curing Days (Age)	Mix by Volume	Failure Load (kN)	Compressive Strength (N/mm²)	Average Compressive Strength (N/mm²)
7 days	1: 2: 4	370.5	16.47	16.05
		362.8	16.12	
		350.4	15.57	
21 days	1: 2: 4	382.8	17.01	17.28
		390.5	17.36	
		392.8	17.46	
28 days	1: 2: 4	400.2	17.79	17.88
		408.3	18.15	
		398.5	17.71	

Table A4: Compressive Strength Test Result for 15%PKS

Curing Days (Age)	Mix by Volume	Failure Load (kN)	Compressive Strength (N/mm²)	Average Compressive Strength (N/mm²)
7 days	1: 2: 4	320.2	14.23	13.79
		310.5	13.8	
		300.4	13.35	
21 days	1: 2: 4	328.8	14.61	14.88
		340.2	15.12	
		335.5	14.91	
28 days	1: 2: 4	350.7	15.59	15.61
		348.3	15.48	
		354.9	15.77	

Table A5: Compressive Strength Test Result for 20%PKS

Curing Days (Age)	Mix by Volume	Failure Load (kN)	Compressive Strength (N/mm ²)	Average Compressive Strength (N/mm ²)
7 days	1: 2: 4	294.7	13.10	13.14
		301.5	13.40	
		290.8	12.92	
21 days	1: 2: 4	311.8	13.86	14.05
		315.5	14.02	
		320.8	14.26	
28 days	1: 2: 4	328.6	14.60	14.69
		330	14.67	
		332.7	14.79	

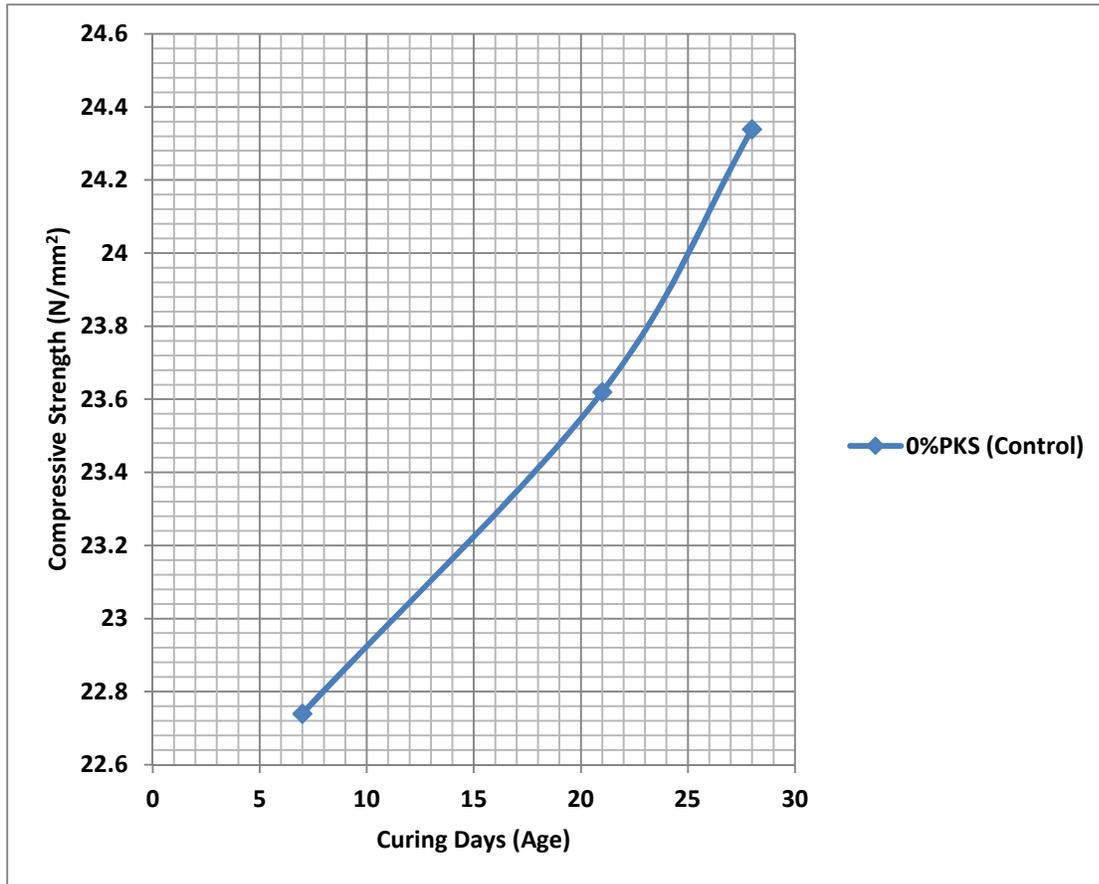


Figure A1: Graph of Compressive Strength against Intervals of Curing Days for 0%PKS Concrete

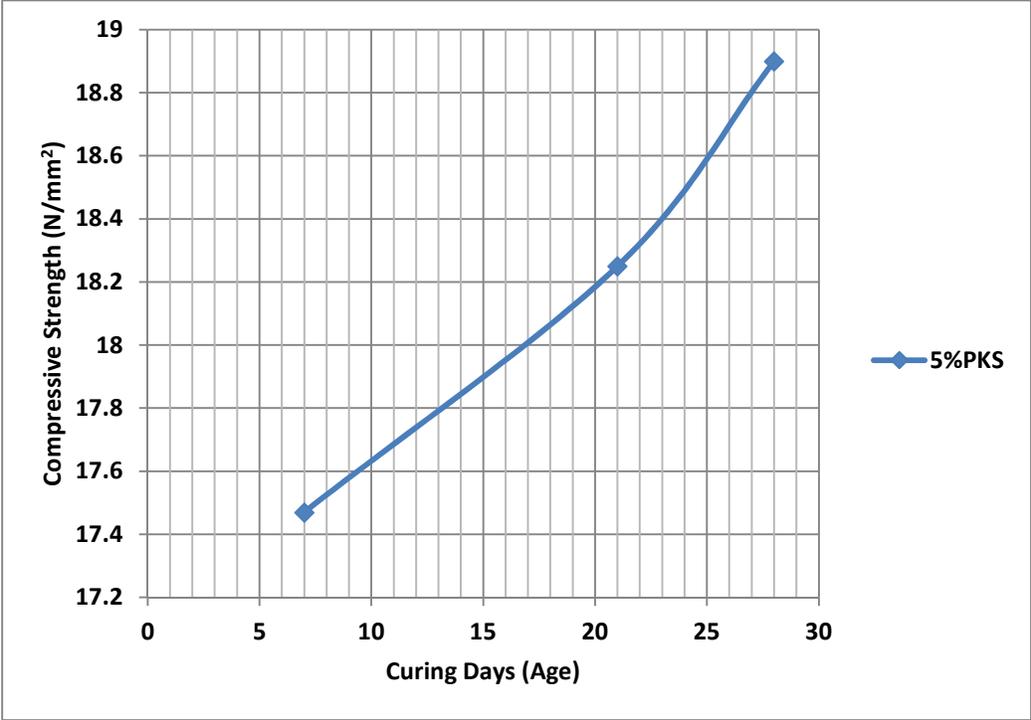


Figure A2: Graph of Compressive Strength against Intervals of Curing Days for 5%PKS Concrete

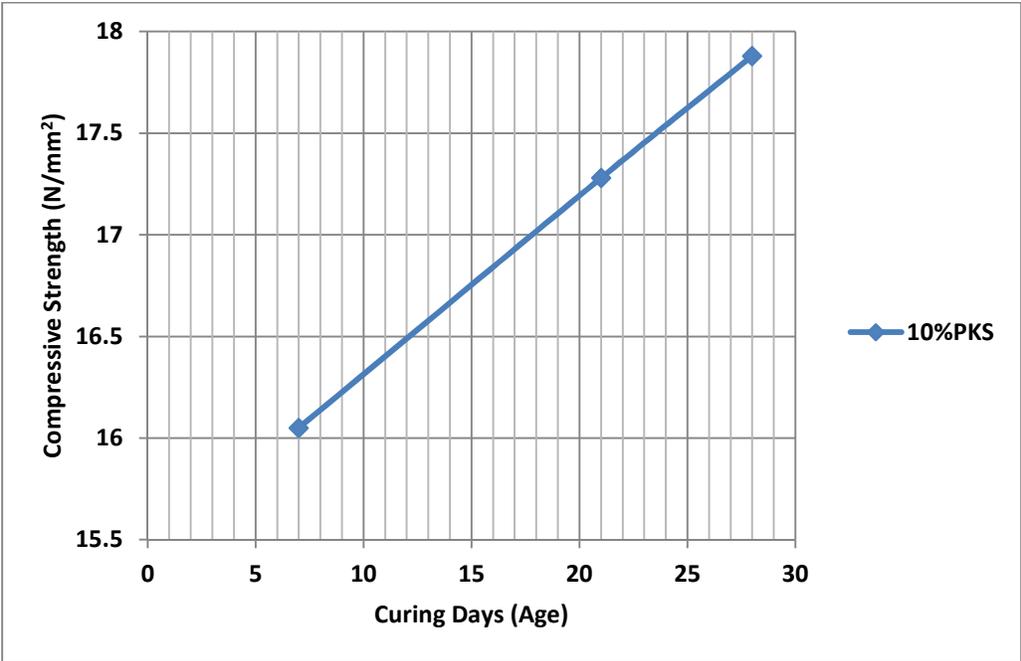


Figure A3: Graph of Compressive Strength against Intervals of Curing Days for 10%PKS Concrete

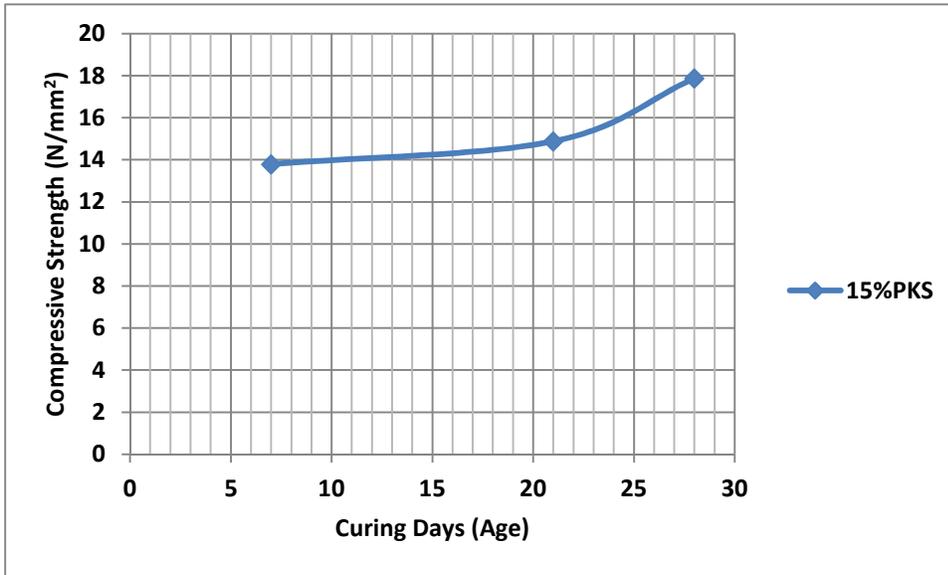


Figure A4: Graph of Compressive Strength against Intervals of Curing Days for 15%PKS Concrete

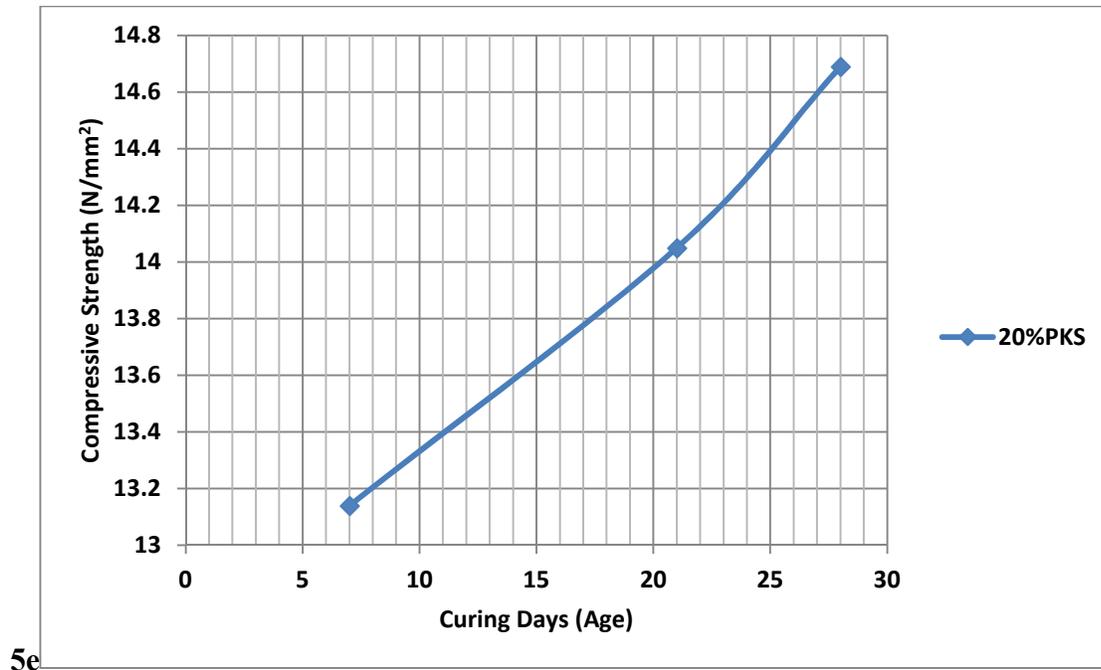


Figure A5: Graph of Compressive Strength against Intervals of Curing Days for 20%PKS Concrete

APPENDIX B

Hardened Concrete Density Test

Table B1: Dry Density Test Results for 0%PKS (Control)

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m³)	Average Density (kg/m³)
7 days	7.08	7.22	2098	2138
	7.25		2148	
	7.32		2169	
21 days	7.84	7.77	2323	2303
	7.56		2240	
	7.92		2344	
28 days	8.12	8.11	2406	2404
	8.08		2394	
	8.14		2412	

Table B2: Dry Density Test Results for 5%PKS

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m³)	Average Density (kg/m³)
7 days	6.58	6.55	1950	1941
	6.62		1961	
	6.45		1911	
21 days	6.72	6.79	1991	2012
	6.8		2014	
	6.85		2030	
28 days	6.92	6.95	2050	2060
	7.04		2086	
	6.9		2044	

Table B3: Dry Density Test Results for 10%PKS

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m³)	Average Density (kg/m³)
7 days	6.14	6.0	1819	1777
	5.95		1763	
	5.9		1748	
21 days	6.24	6.27	1849	1859
	6.30		1867	
	6.28		1861	
28 days	6.52	6.46	1932	1913
	6.45		1911	
	6.40		1896	

Table B4: Dry Density Test Results for 15%PKS

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m³)	Average Density (kg/m³)
7 days	5.82	5.76	1724	1706
	5.75		1704	
	5.70		1689	
21 days	5.92	5.96	1754	1765
	6.05		1793	
	5.9		1748	
28 days	6.14	6.21	1819	1819
	6.0		1778	
	6.28		1861	

Table B5: Dry Density Test Results for 20%PKS

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m ³)	Average Density (kg/m ³)
7 days	5.35	5.24	1585	1553
	5.22		1547	
	5.15		1526	
21 days	5.22	5.53	1636	1638
	5.62		1665	
	5.44		1612	
28 days	5.73	5.73	1698	1700
	5.82		1724	
	5.64		1671	

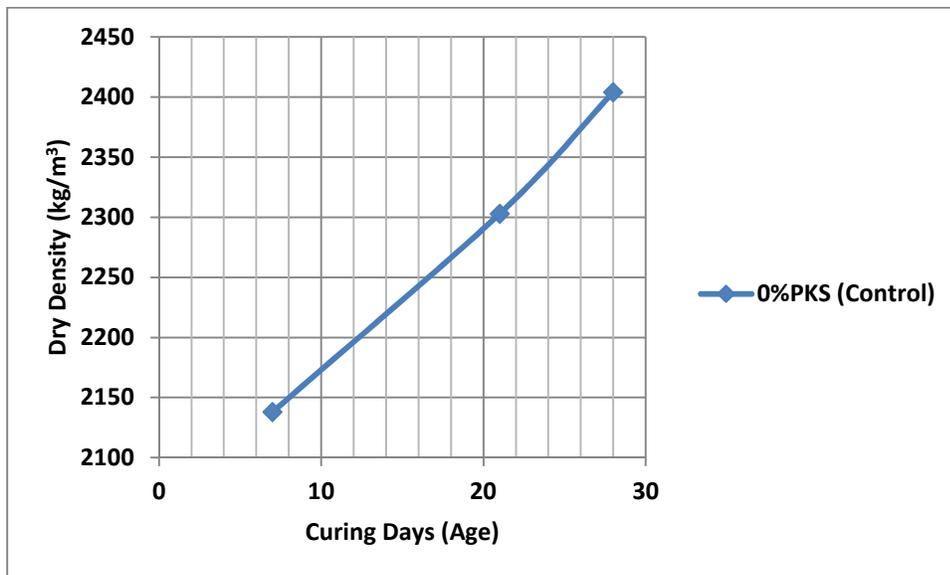


Figure B1: Graph of Dry Density against Intervals of Curing Days for 0%PKS Concrete

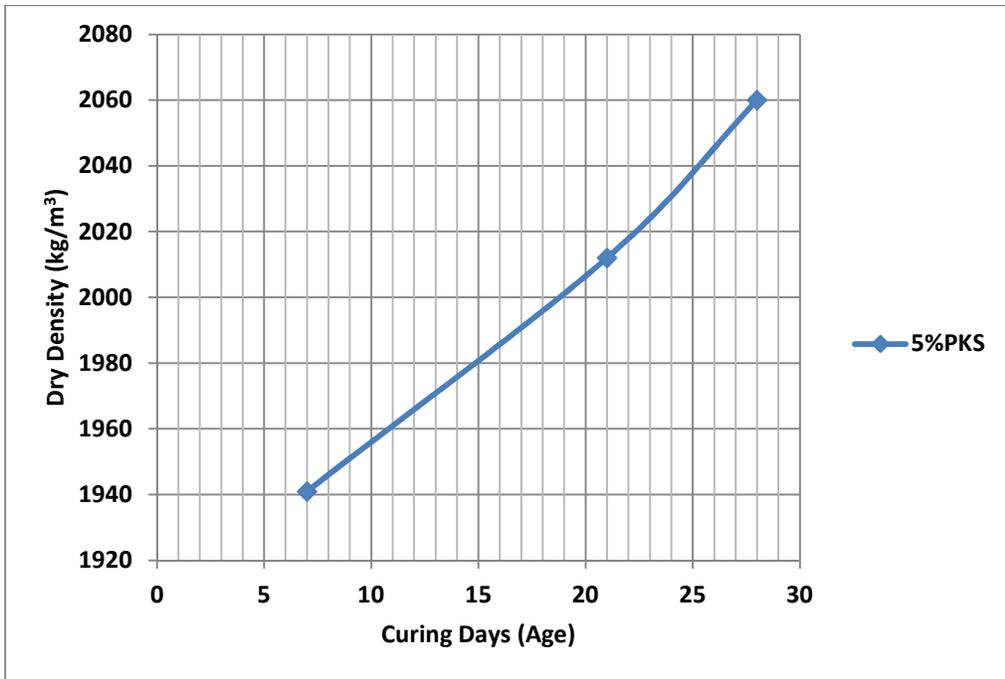


Figure B2: Graph of Dry Density against Intervals of Curing Days for 5%PKS Concrete

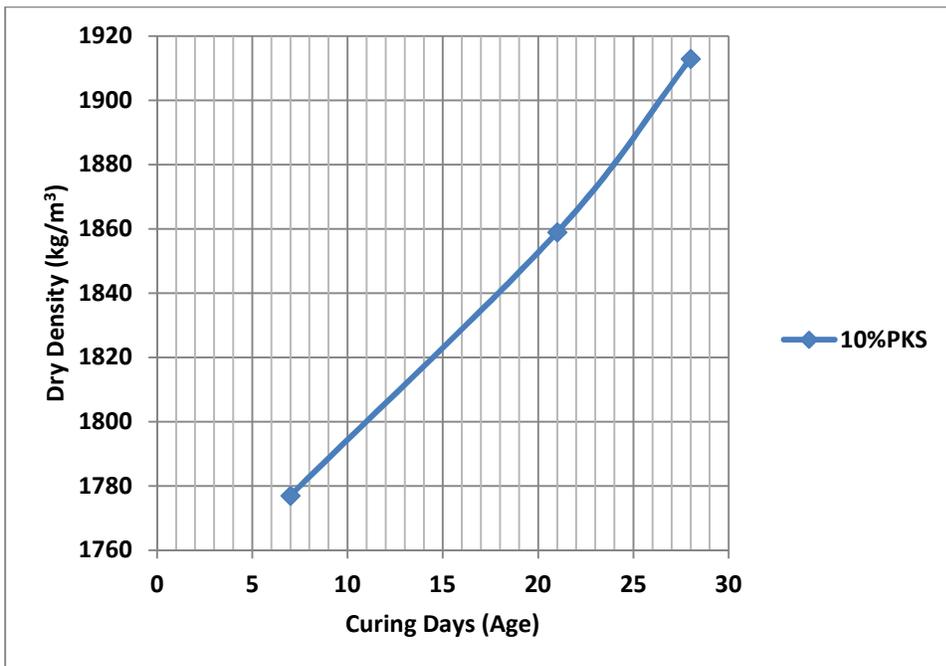


Figure B3: Graph of Dry Density against Intervals of Curing Days for 10%PKS Concrete

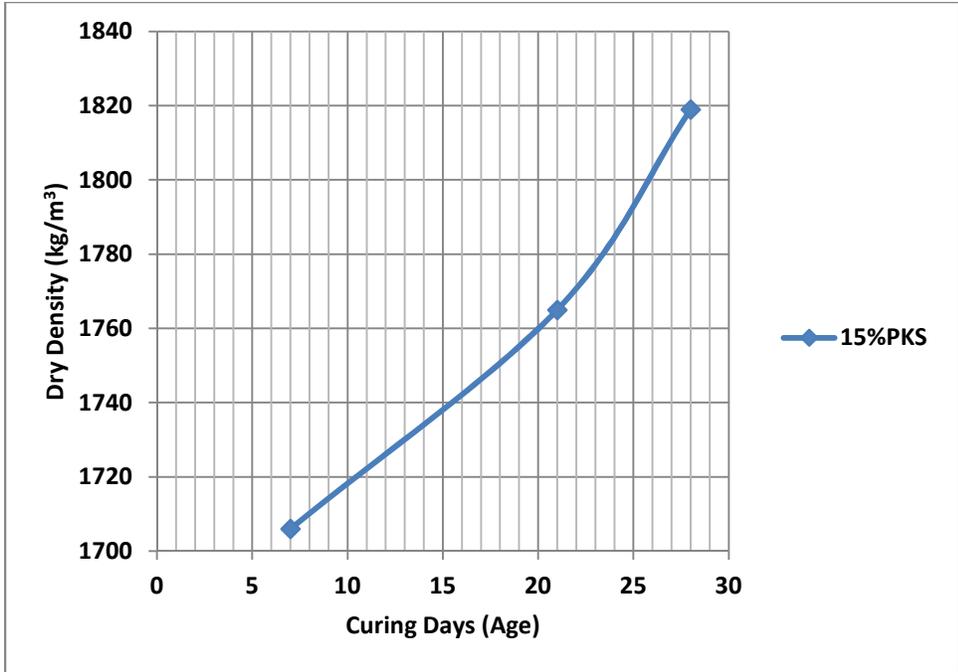


Figure B4: Graph of Dry Density against Intervals of Curing Days for 15%PKS Concrete

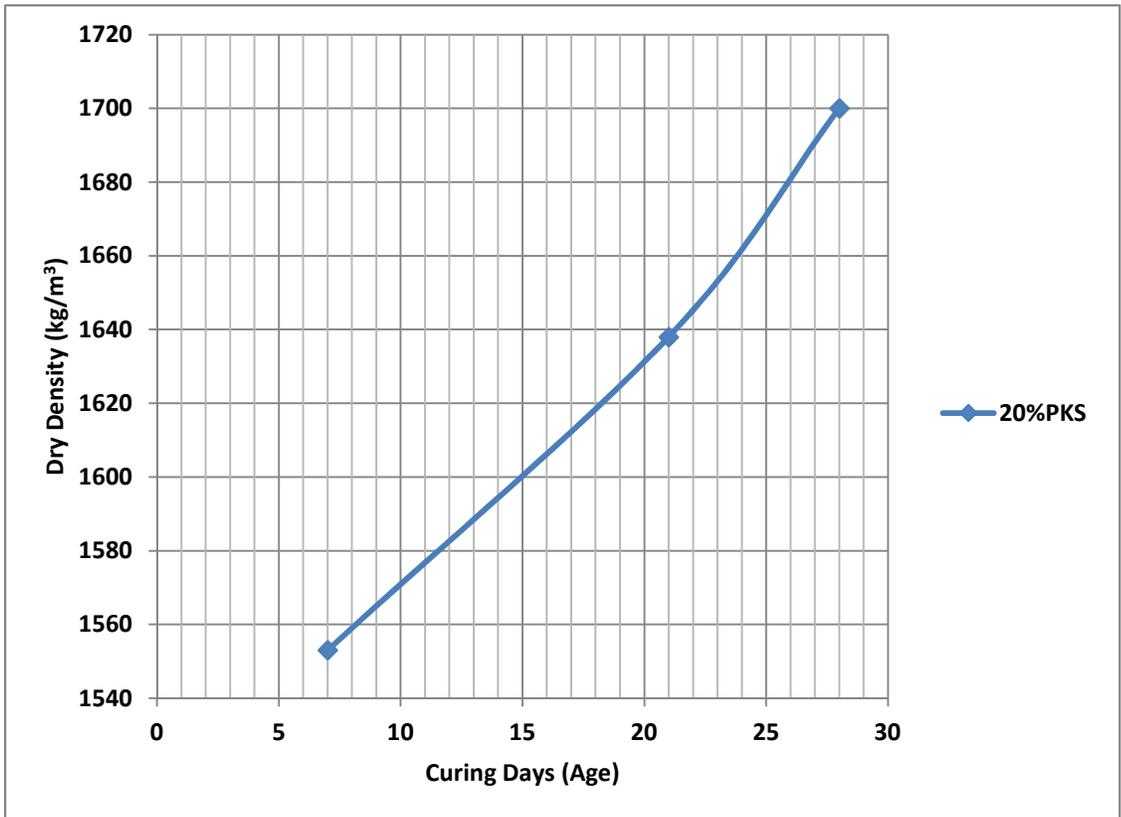


Figure B5: Graph of Dry Density against Intervals of Curing Days for 20%PKS Concrete

APPENDIX C

Wet Density of Concrete Cubes

Table C1: Wet Density Test Results for 0%PKS (Control)

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m³)	Average Density (kg/m³)
7 days	7.24	7.31	2145	2165
	7.30		2163	
	7.38		2187	
21 days	7.94	7.86	2353	2328
	7.66		2270	
	7.97		2361	
28 days	8.21	8.19	2433	2428
	8.15		2415	
	8.22		2436	

Table C2: Wet Density Test Results for 5%PKS

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m³)	Average Density (kg/m³)
7 days	6.72	6.78	1991	2008
	6.84		2027	
	6.77		2006	
21 days	6.93	6.96	2053	2063
	6.95		2059	
	7.01		2077	
28 days	7.24	7.17	2145	2123
	7.18		2127	
	7.08		2098	

Table C3: Wet Density Test Results for 10%PKS

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m³)	Average Density (kg/m³)
7 days	6.35	6.25	1881	1852
	6.22		1843	
	6.18		1831	
21 days	6.43	6.51	1905	1929
	6.52		1932	
	6.58		1950	
28 days	6.84	6.78	2027	2010
	6.78		2009	
	6.73		1994	

Table C4: Wet Density Test Results for 15%PKS

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m³)	Average Density (kg/m³)
7 days	6.24	6.17	1849	1827
	6.18		1831	
	6.08		1801	
21 days	6.32	6.37	1873	1887
	6.38		1890	
	6.41		1899	
28 days	6.42	6.41	1902	1899
	6.28		1861	
	6.53		1935	

Table C5: Wet Density Test Results for 20%PKS

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m³)	Average Density (kg/m³)
7 days	5.58	5.53	1653	1638
	5.53		1639	
	5.47		1621	
21 days	5.79	5.79	1716	1717
	5.87		1739	
	5.72		1695	
28 days	6.05	6.14	1793	1820
	6.24		1849	
	6.14		1819	

APPENDIX D

Water Absorption Test

Table D1: Water Absorption Test Results for 0%PKS (Control)

Curing days (Age)	Water Absorption (%)	Average Water Absorption (%)
7 days	2.26	1.26
	0.69	
	0.82	
21 days	1.28	1.08
	1.32	
	0.63	
28 days	1.11	0.97
	0.87	
	0.98	

Table D2: Water Absorption Test Results for 5%PKS

Curing days (Age)	Water Absorption (%)	Average Water Absorption (%)
7 days	2.13	3.47
	3.32	
	4.96	
21 days	3.13	2.56
	2.21	
	2.34	
28 days	4.62	3.26
	2.56	
	2.61	

Table D3: Water Absorption Test Results for 10%PKS

Curing days (Age)	Water Absorption (%)	Average Water Absorption (%)
7 days	3.42	4.24
	4.54	
	4.75	
21 days	3.04	3.77
	3.49	
	4.78	
28 days	4.91	5.06
	5.12	
	5.16	

Table D4: Water Absorption Test Results for 15%PKS

Curing days (Age)	Water Absorption (%)	Average Water Absorption (%)
7 days	7.22	7.12
	7.48	
	6.67	
21 days	6.76	6.75
	5.45	
	8.04	
28 days	4.56	4.40
	4.67	
	3.98	

Table D5: Water Absorption Test Results for 20%PKS

Curing days (Age)	Water Absorption (%)	Average Water Absorption (%)
7 days	4.30	5.48
	5.94	
	6.21	
21 days	4.89	4.83
	4.45	
	5.15	
28 days	5.58	7.22
	7.22	
	8.87	

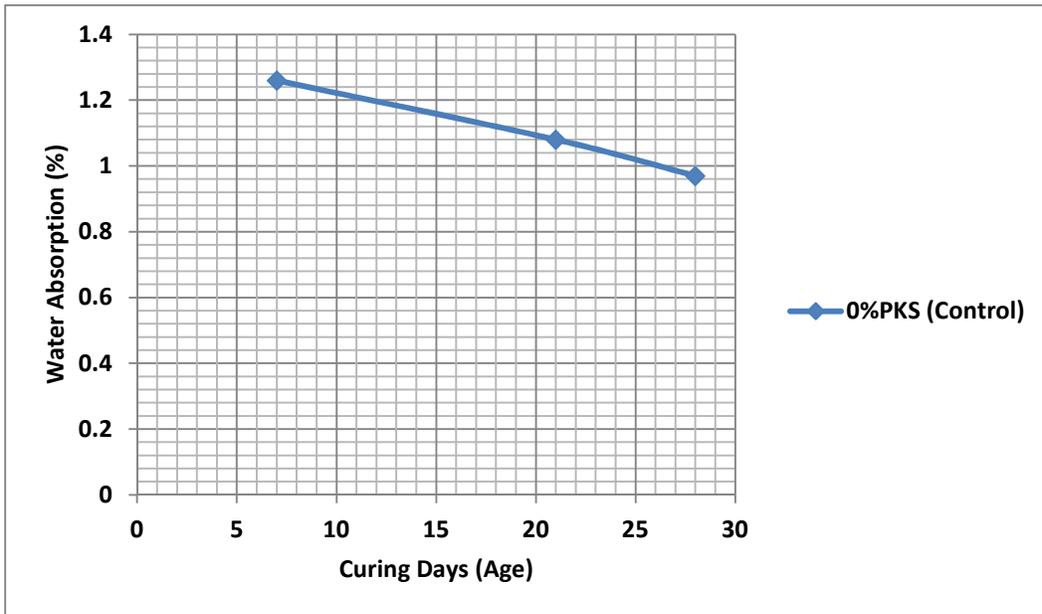


Figure D1: Graph of Water Absorption against Intervals of Curing Days for 0%PKS Concrete

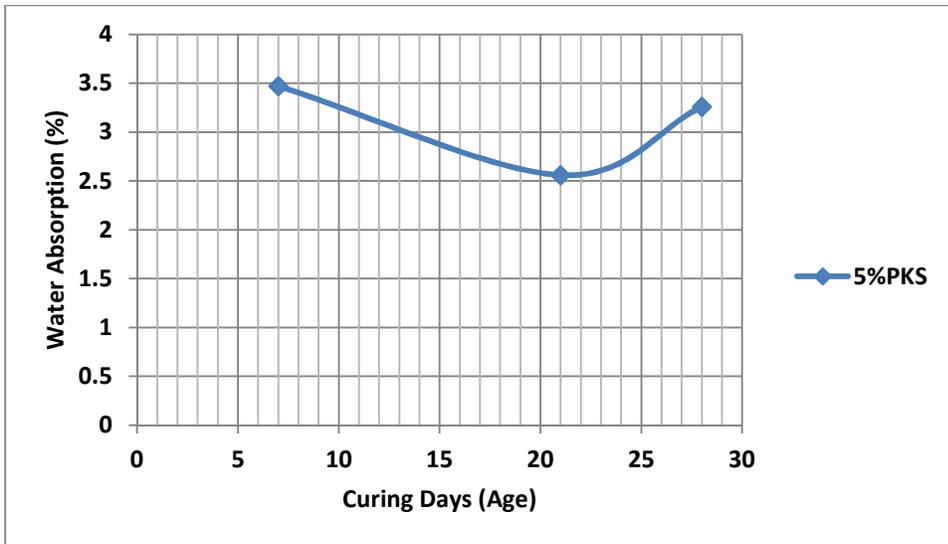


Figure D2: Graph of Water Absorption against Intervals of Curing Days for 5%PKS Concrete

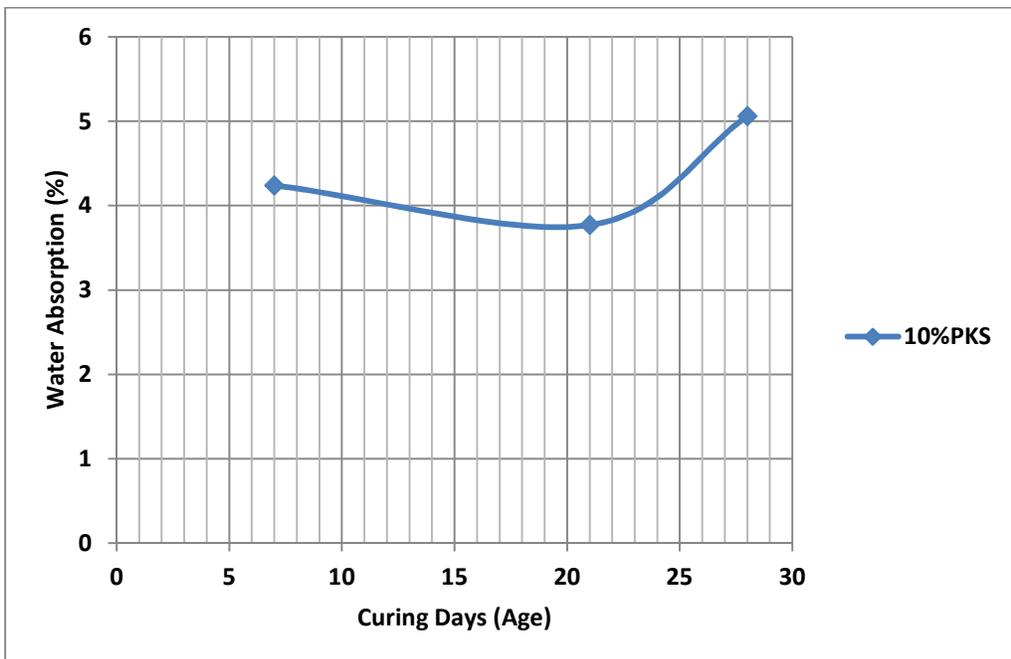


Figure D3: Graph of Water Absorption against Intervals of Curing Days for 10%PKS Concrete

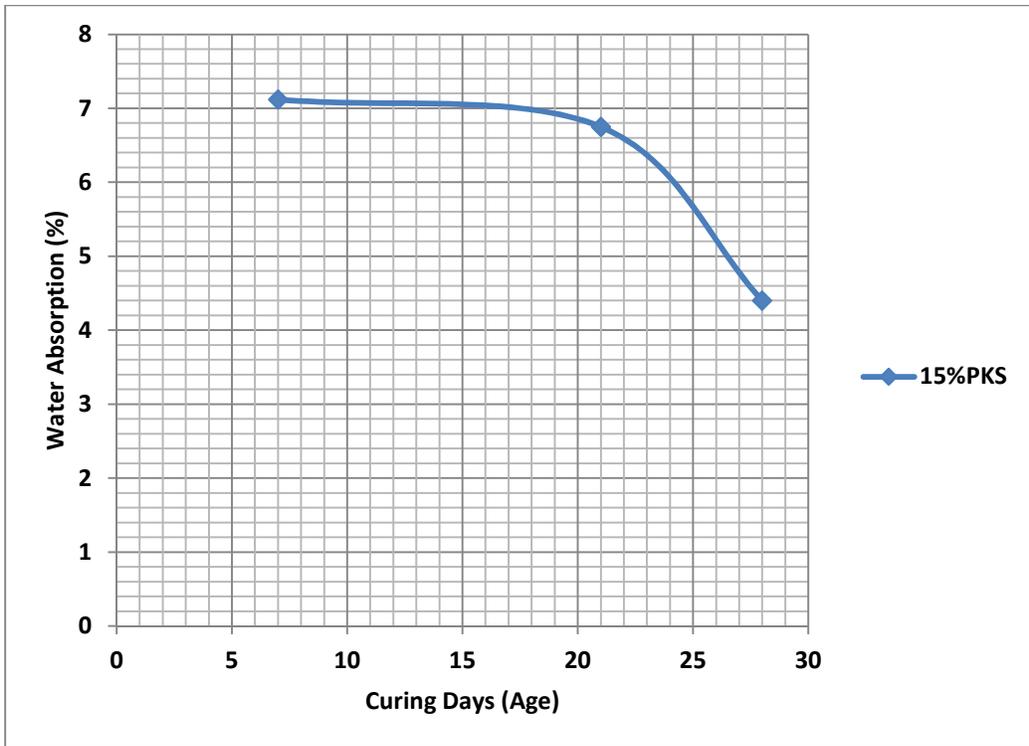


Figure D4: Graph of Water Absorption against Intervals of Curing Days for 15%PKS Concrete

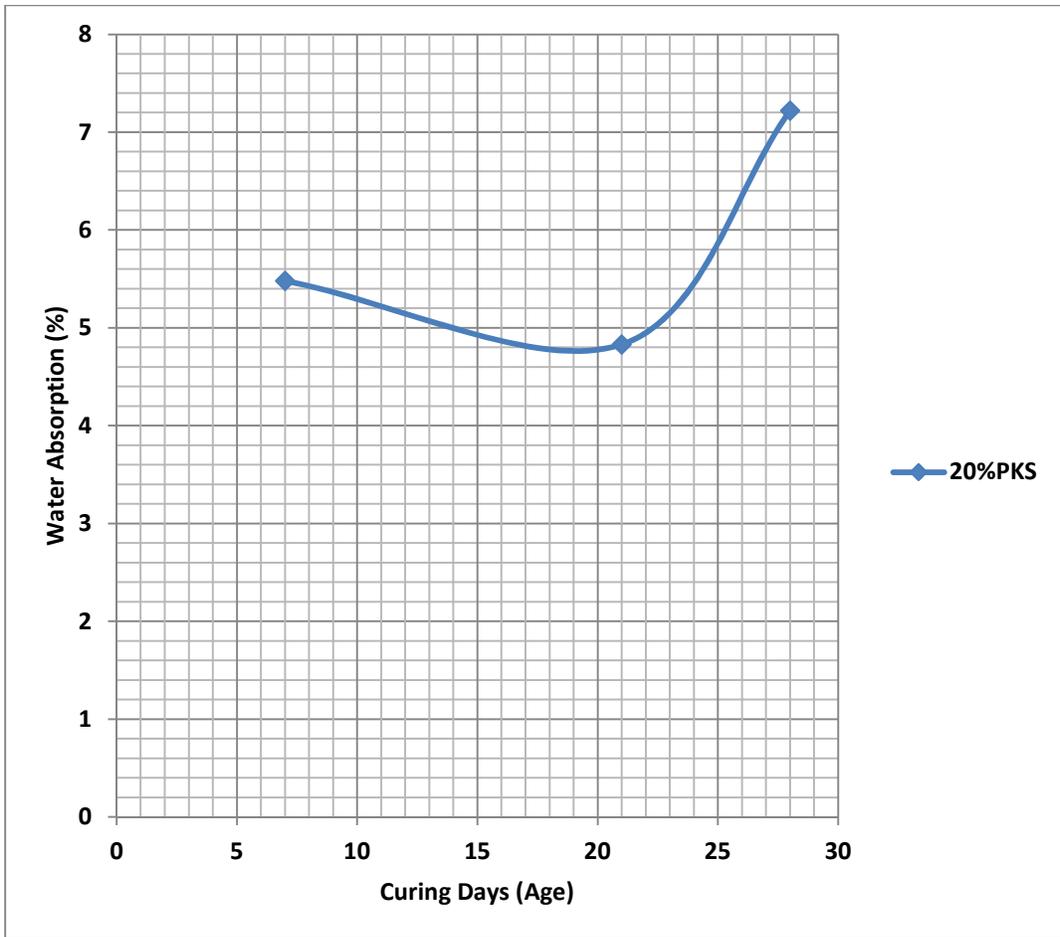


Figure D5: Graph of Water Absorption against Intervals of Curing Days for 20%PKS Concrete

APPENDIX E

Pictures showing some practical done during the course of the project



Plate 1E: Batching in progress.



Plate 2E: Concrete mixing in progress.



Plate 3E: Cube naming in progress.



Plate 4E: Slump Determination.



Plate 5E: Removing cubes from curing can.

Plate 6E: Compressive strength Test Ongoing.

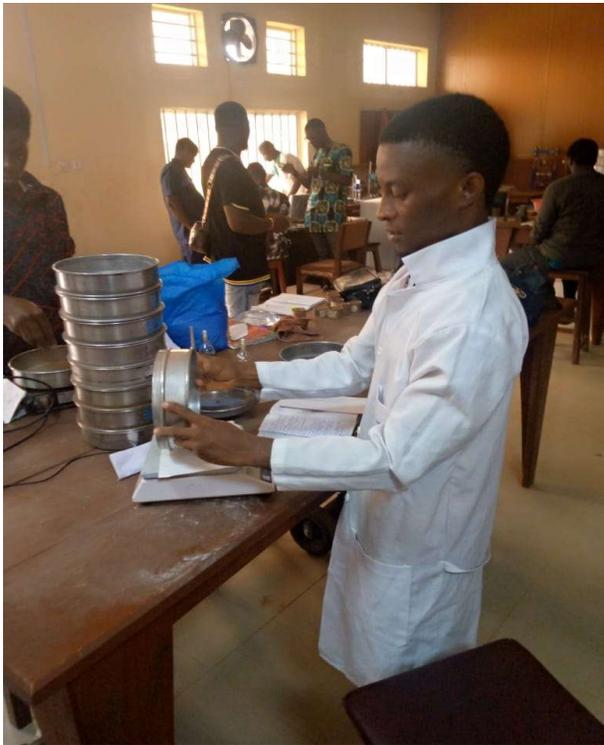


Plate 7E: Sieve Analysis of Aggregates in progress.