STRENGTH AND MICROSTRUCTURE OF LATERITIC CONCRETE CONTAINING PALM KERNEL SHELL (PKS) AS PARTIAL REPLACEMENT FOR COARSE AGGREGATES.

BY

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ABSTRACT

This research work reports the investigation carried out to determine the strength and microstructure of lateritic concrete containing palm kernel shell (PKS) as partial replacement of coarse aggregates. The study employed different mix proportions, which resulted in casting and testing 148 cubes at 7, 14, 21, 28, 60, and 90-days of curing, to determine the best and economic proportion that will give compressive strength. The materials and methodology phase of this research evaluated the physical and mechanical properties of aggregates, fresh concrete properties such as slump, mechanical properties of hardened concrete, such as, compressive strength and density, sorptivity and the microstructural properties of concrete. In the study of the physical and mechanical properties of the aggregates, it was revealed that the PKS aggregate exhibited low specific gravity, bulk density, impact, and abrasion value of 1.33, 661 kg/m^3, 0.6% and 0.85% as compared with granite 2.74, 1660 kg/m^3, 0.98% and 1.97% respectively. While, the laterite aggregate exhibited low porosity, bulk density and specific gravity value of 11.39%, 1220 kg/m^3 and 2.18 as compared with sand 25%, 1786 kg/m^3, and 2.76 respectively. The concrete specimen were produced with PKS and granite as coarse aggregate, laterite and ordinary river sand as fine aggregate and ordinary Portland cement as binder. Mix ratio of 1:2:4 and water cement ratio 0.5, were used in the concrete production. The 28-day compressive strength of the concrete produced in this study was found to satisfy the minimum strength requirements of structural concrete based on BS 8110 at 0% - 10% PKS content. The result obtained and the observations made from the sorptivity test indicated that the increase in PKS content increased the sorptivity of the concrete proportionally, which is disadvantageous to concrete, especially in marine or water prone environment. The SEM/EDX result indicated that inclusion of PKS in the concrete affects the bonding between the binding medium and the aggregates such as, granite and sand. While, the EDX result showed that the concrete contained elements such as calcium, alumina, silica, oxides and sulphur. It is concluded that PKS aggregates can be used in the production of lateritic concrete at 0% - 10% respectively, but further increase in PKS content would negatively affect the concrete's strength.

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DEDICATION

I dedicate this project to GOD almighty my creator, my strong pillar, my source of inspiration, wisdom, knowledge, and understanding. I also dedicate this project to my parents (Alhaji S.O. Bello and Alhaja R.B. Bello) for their supports and their encouragement.

DECLARATION

This project is a result of my own work and has not been copied in part or in whole from any other source except where duly acknowledged. As such, all use of previously published work (from books, journals, magazines, internet and so on) has been acknowledged within the main report to an entry in the References list.

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CERTIFICATION

This is to certify that this project entitled "STRENGTH AND MICROSTRUCTURE OF LATERITIC CONCRETE CONTAINING PALM KERNEL SHELL (PKS) AS PARTIAL REPLACEMENT FOR COARSE AGGREGATES" by BELLO, HUSSEIN ABDULRAHEEM (CVE/12/0827), submitted in partial fulfillment of the requirements for the degree of Bachelor of Engineering (B. ENG.) in CIVIL ENGINEERING of Federal University, Oye-Ekiti, during the academic year 2012-2017, is a bonafide record of work carried out under my guidance and supervision.

Dr. Christopher A. Fapohunda	....	11-12-2017
(Project Supervisor)	Signature	Date
Prof. Joseph Babalola Adeyeri	....	....
(Head of Department)	Signature	Date

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LIST OF ABBREVIATIONS

AAV	Aggregate Abrasion Value
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
ASTM	American Society for Testing Materials
BS	British Standard
EDS	Energy Dispersive Spectroscopy
EDX	Energy Dispersive X-ray Spectroscopy
I.S	Indian Standard
LWC	Light Weight Concrete
OPC	Ordinary Portland Cement
OPS	Oil Palm Shell
PKS	Palm Kernel Shell
SEM	Scanning Electron Microscopy
WC	Water Content
W/C	Water Cement ratio

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CHAPTER ONE

INTRODUCTION

1.0 Background

Concrete is a composite material that consists essentially of a binding medium, such as a mixture of Portland cement and water, within which are embedded particles or fragments of aggregate, usually a combination of fine and coarse aggregate. Concrete's versatility, durability, sustainability, and economy have made it the world's most widely used construction material. It can be engineered to satisfy a wide range of performance specifications, unlike other building materials, such as natural stone or steel, which generally have to be used as they are.

Nigeria being a developing country is faced with inadequate provision of physical infrastructure; shelter and related amenities, which are typical factors of under development that need to be addressed through provision of alternative, cheap and affordable materials. In recent times, shelter conditions have become worse; resources have remained scarce and housing demand has increased due to increase in population. Thus, the need to provide immediate practical solutions have become more urgent (Kerali 2001) Adequate shelter is one of the most important basic human needs, yet about 25% of the world's population do not have any fixed abode, and in African cities the housing shortage ranges from 33% to 90% (Zami and Lee 2008).

There have been efforts by the governments at various levels carrying out the policy of direct intervention into the provision of shelter by building low cost housing units. Apparently, significant progress in these schemes was seemingly impossible as a result of challenges posed by continued rising cost of conventional structural materials as well as geometrical growth of population, especially in urban areas. This has led to the quest for alternative cheaper materials. In this quest, various forms of building materials like burnt clay bricks, timber construction, were suggested based on the availability of raw materials for these form of construction in various part of the country. Therefore, the emphasis in Nigeria should be in the use of alternative to major constituent materials in concrete and blocks, such as steel in form of reinforcement rods and rolled sections, bricks, laterite blocks, granite, gravel, Yoyo sand, cement, pozzolanas, palm fibre, coconut fibre and bamboo. (M. A. Salau 2008)

1.1 Alternatives to Aggregates in the Production of Structural Concrete

1.1.0 Palm kernel shell as a coarse aggregate in concrete.

The rise in the need for concrete in the construction industry using natural weight aggregate such as granite or gravel has greatly reduced the availability of natural stone and has led to the damage of the environment, leading to imbalance of the ecological system. The use of agricultural and industrial wastes to complement other traditional materials in construction provides both practical and economic advantages. The wastes generally have no commercial value and being locally available transportation cost is minimal.

Palm Kernel Shell (PKS) is a waste material obtained during the crushing of palm nuts in the palm oil mills for palm oil extraction. Utilizing PKS would impose lower construction costs compared to other waste materials like rubber crump, plastic waste, and others. With proper mix design, PKS can be utilized to develop normal strength concrete, which ranges from 20 to 30MPa. (Shafigh, Jumaat and Mahmud 2010) Research has been conducted on PKS as lightweight aggregate to produce lightweight concrete. (Alengaram 2013) Which brought immense changes in the concrete industry. It was discovered by (Imam and Nura 2014) that palm nut shell can be used as construction material in low cost buildings since it has attained a compressive strength of $18N/mm^2$. This can indirectly facilitate in waste reduction. This research focuses on the contribution of PKS in the improvement of concrete performance in terms of workability, water absorption, density, and compressive strength.

1.1.1 Laterite as fine aggregate for concrete

Sand has traditionally been used as fine aggregate in structural concrete. The commonest types of sand used in this regard in various parts of Nigeria are river sand, erosion sand, and dune sand (dug-out sand). Unfortunately, these sand types are not readily available in many parts of the country, and could be rightly regarded as scarce material for concrete-making in those communities. Persons making concrete in such localities usually import sand from relatively distant places at high costs, and this increases the overall cost of making concrete and of providing housing for the people. Thus, there is an increasing need to source alternative locally-available materials that could serve as suitable replacement to sand as fine aggregate in concrete.

Laterite has the advantage of being readily available in most Nigerian communities. Besides being obtained intentionally in burrow pit excavations, it is also frequently obtained through various forms of excavations for substructure works, including excavations for foundations and septic tanks. However, unlike sand, laterite is a combination of different soil types, notably clay, sand, and silt. The presence of clay and silt particles in large quantities could make laterite fall short of the requirements of BS 882 for high quality concrete. Thus, the suitability or otherwise of using laterite as sole replacement for sand in concrete would depend greatly on the proportion of these fine particles in the laterite.

1.2 Statement of Problem

Production of concrete relies to a large extent on the availability of cement, sand and coarse aggregates. The costs of which have risen astronomically over the past few years, this led to the continuous increase in the cost of construction and it's one of the major challenges the construction industry is facing and quality discharge of great number of developmental project, as such projects are dependent on some factors of production which is the cost of materials. This rising in construction costs necessitated research into the use of alternative materials, especially locally available ones which can replace conventional ones used in concrete production. The use of such replacement materials should be able to reduce the cost of construction.

Due to the growth in population, the amount and type of waste materials have increased accordingly, many of the agricultural and industrial wastes have created waste management and pollution problems. However the use of these agricultural and industrial wastes to complement other traditional materials in concrete production may provide economic advantages, and foreseeable solution to the challenges of waste management.

Natural resources management and environment protection. More than 3.8 billion cubic meters concrete is produced globally, this requires a lot of natural resources for producing cement and aggregates, and over one trillion gallon of water is used each year globally. One ton of cement releases one ton of CO_2 into the atmosphere which contributes to global warming. The use of waste materials in construction would help conserve natural resources and protect of the environment.

The focus of this research is to tackle the following questions:

i. Can palm kernel shell and laterite be used in concrete production?
ii. If yes, at what proportion can it be used that concrete would retain its structural competence and is it environmental friendly?
iii. What positive or negative impact does it have on concrete production?

1.3 Aim

The aim of this project is to determine the microstructure and the structural capacity of laterite concrete replacing granite in a proportionate amount with palm kernel shell for structural application in the construction industry.

1.4 Objectives

The objectives set to achieve this aim are as follows;

i. Preliminary investigation to characterize materials to be used for the research.
ii. To study the fresh state properties of lateritic concrete containing palm kernel shell (PKS) as coarse aggregate such as, workability.
iii. To study the hardened state properties of lateritic concrete containing palm kernel shell (PKS) as coarse aggregate such as, density, compressive strength, sorptivity and microstructure of concrete.
iv. To investigate to what proportion would granite aggregate of a lateritic concrete be replaced with Palm Kernel Shell (PKS) and still retain it structural competence.

1.5 Significance of Research Project

This research would help determine the extent at which palm kernel shell would replace coarse aggregate of laterite concrete without reducing its structural competence. Thus this would;

i. Increase agricultural waste product use in concrete industry.
ii. Reduce environmental pollution and promote sustainable development.
iii. Reduce cost of concrete production

1.6 Scope of Project

The scope of this work is limited to the following;

i. Test of mechanical and physical properties of aggregates such as palm kernel shell (PKS), granite, sand and laterite.
ii. Test of compressive strength of the laterized concrete containing PKS as coarse aggregate.
iii. The sorptivity and water absorption properties of concrete cubes.
iv. The microstructural properties of the laterite concrete containing PKS as coarse aggregate.

CHAPTER TWO

LITERATURE REVIEW

Concrete is a construction material manufactured by mixing fine aggregate (sand), coarse aggregate (crushed stone and gravel), cement and water either in a designed or prescribed proportion. It is strong in compression and has good fire resisting properties, and when steel, which is strong in tension is incorporated into it, a strong and durable material which can withstand various forms of loading and can be formed into various shapes and sizes emerges. This accounts for its widespread use in civil engineering construction works such as buildings, bridges, dams, roads and so on.

One drawback, however, is that its massive production exerts negative effects on the environment. Its main ingredients, that is cement and aggregate material, need to be produced and mined on massive scale and transported over considerable distances increasing energy consumption, greenhouse gas emissions and landscape mutilation (Jonkers, *et al.*, 2010). It is estimated that cement (Portland clinker) production alone contributes 7% to global anthropogenic CO_2 emissions, what is particularly due to the sintering of limestone and clay at a temperature of 1500°C, as during this process calcium carbonate (CaCO3) is converted to calcium oxide (CaO) while releasing CO_2 (Worrell *et al.*, 2001). Therefore, from an environmental viewpoint, concrete does not appear to be a sustainable material (Gerilla *et al.*, 2007). As a result, the concrete construction can make significant negative impacts over the environment.

Therefore, sustainability is a key issue for the global concrete industry. Achieving sustainability has become more and more important question all over the world during the last decade. It is well known that sustain means to support or to maintain a process going, and the objective of sustainability is that life on the universe can be sustained for the projected future. Environment, economy, and society are the components of sustainability. At the present time, the environment is probably the most important component, and an engineer or architect exercises sustainability to reduce negative impact on the environment (Adeyemi 2014). Large amounts of low cost building materials (Portland cement concrete) is required for the construction of infrastructure due to rapidly industrialising world and this trends will be continued. The unlimited use of natural resources and huge amounts of environmental pollution is a principal caution for the preservation of the life sustaining environment on the globe.

The sustainable concrete is associated with reduction of the amount of polluting and CO2 gases emitted during the concrete production, use of waste material in more efficient way, development of low-energy, long-lasting, flexible buildings and structures exploiting the thermal mass of concrete in a structure to reduce energy demand (Sustainable Concrete 2017). Two main actions that meet the needs for sustainable construction development are; A sensible use of natural resources that can be achieved by the use of by-products and reusable materials, and a lower environmental impact that will be gained through reduced carbon dioxide emission and reduced natural resources extraction from quarries (Moriconi 2007).

The study on the compressive strength of laterized concrete using palm kernel shells as partial replacement of coarse aggregate in which the crushed rock component of laterized concrete is replaced partially by palm kernel shells considered contributions made by other researchers regarding the introduction of lateritic sand and palm kernel shells in concrete works. (Idagu *et al.*, 2016)

(Daniel and Emmanuel 2012) in their research conducted on palm kernel shell as a coarse aggregate in concrete, concluded that workability of concrete reduced as palm kernel shell content increased due to the increase in the specific surface as a result of increase in quantity of palm kernel shell, thus requiring more water to make the mix workable. The data obtained from the crushing test on the concrete indicated that the compressive strength decreased with the increment of palm kernel shell content. The compressive strength is maximum at 0% replacement by palm kernel shell and minimum at 100% replacement, with compressive strength of 24.02 N/mm2 and 1.84 N/mm2 respectively at 28 days of age. Based on the results obtained, replacement of 8% crushed granite by kernels shell in volume-batched concrete can be used in reinforced concrete construction whereas replacement of 13% if crushed granite in weight batched concrete can be used in reinforced concrete construction.

The experimental study conducted by (Zarina *et al.*, 2016) on the feasibility of palm kernel shell as replacement for coarse aggregate in lightweight concrete, five mixes were cast replacing granite with palm kernel shell. Based on the result of the slump test it was concluded that the workability of concrete reduced linearly as the amount of palm kernel shell percentage increases, since normal aggregate is denser than palm kernel shell aggregate, and the replacement is by weight, thus the specific surface increases as the palm kernel shell content increases. This resulted into the increase in requirement of cement paste for the lubrication of the aggregate, which therefore reduces the entire fluidity of the mix, thereby reducing the height of the slump.

The result obtained from the water absorption test indicated that water absorption for concrete containing palm kernel shell increased but was still within standard ranges.

The crushing test result indicated that the inclusion of palm kernel shell reduced the strength of the concrete, but by the replacement of 50% palm kernel shell this gave acceptable values as it fell within the range requirement for structural lightweight concrete.

(Idagu et. al., 2016) investigated the compressive strength of laterized concrete using palm kernel as partial replacement of coarse aggregate, the result of compressive strength test revealed that the compressive strength at 28 days for Lateritic concrete with 0% PKS replacement at 0.6 W/C ratio was 24.72 N/mm2 while at 0.75 W/C there was a decrease in compressive strength to 17.56 N/mm2 it can be observed that the change In W/C ratio not only affects the workability of laterized concrete, but also its compressive strength, with partial replacement of crushed aggregate with PKS at 0.75 W/C for 15% and 25%, the compressive strength was gotten to 13.67N/mm2 and 10.67 N/mm2 respectively. Highlighting a gradual decrease in compressive strength as PKS percentage replacement increases.

The result obtained from slump test indicated that with the continuous increase in quantity of PKS replacement, workability decreases gradually (that is at 0.75 W/C slump values for 0%, 15%, and 25% partial replacement were 43.33mm, 23.30mm and 10.67mm respectively). It was also revealed from the water absorption test that the percentage water absorbed increased with increase in the amount of PKS in the mix. High water absorption value of PKS lead to increase in percentage water absorbed by the mix with 25% PKS used to replace coarse aggregate.

In the investigation conducted by (Owolabi 2012) "Palm kernel shell as aggregate in concrete and laterite blocks", the grading curve of the particle size distribution of aggregates for palm kernel shells and crushed stone aggregates revealed that for crushed stone the coefficient of uniformity was 6 while the coefficient of curvature was 1. This showed that the crushed stone aggregate used was well graded with sizes ranging from 0.4 mm to 30 mm. For kernel shells, the coefficient of uniformity was

2.3 and coefficient of curvature was 1.35, showing that the kernel shells used were gap graded with sizes ranging from 0.5 mm to 30 mm, falling within the medium/coarse sand fraction and the fine/medium gravel fraction.

Tests on palm kernel shells revealed low specific gravity, high moisture content and water absorption rate. Concrete with crushed stone as coarse aggregate has higher strength than concrete with palm kernel shells as aggregate. This shows that palm kernel shells cannot be substituted for crushed stones as coarse aggregate in concrete except for aesthetic purposes. However, concrete with palm kernel shells as aggregate could be used for lightweight construction work.

(Alawode and Idowu 2011) Investigated the effects of water-cement ratio on the compressive strength and workability of concrete and laterized concrete mixes to evaluate the compressive strength and workability. Cube and slump tests were carried out for mix proportion 1:2:4, comparison between laterized concrete and concrete were made in variation of weight, density and compressive strength of mixes, it was reported that for a 28 day cured cube of mix proportion 1:2:4, for concrete of water/cement ratio of 0.55, density of cube was 2.488g/cm3 and compressive strength of 20.00N/mm2 while for laterized concrete of water cement ratio 0.55, density of cube 8.600 g/cm3, compressive strength 38.13N/mm2. Concrete of water cement ratio 0.60, 0.65, 0.70, 0.80 had compressive strength of 17.33N/mm2, 17.11N/mm2, 16.31N/mm2 and 16.00N/mm2 respectively while laterized concrete of water cement ratio 0.6, 0.65, 0.70, 0.8 had compressive strength of 37.47N/mm2, 37.02N/mm2, 6.13N/mm2 and 5.64N/mm2 respectively, from the results above it can be observed that from water cement ratio 0.65-0.70 there is a significant reduction in compressive strength by 83.44% in the laterized concrete which is not applicable to concrete. It was observed that the highest compressive strength of laterized concrete, 38.13N/mm2 was obtained for 1:2:4 mixes at 0.55 water cement ratio. The effect of water cement ratio on the workability of concrete and laterized concrete, from the slump test performed the slump of water cement ratio of 0.55 to 0.70 were classified true slumps in concrete mixes, while for 0.80 water cement ratio; the water content was such that the fluidity of the mixture was large enough to cause collapse of the concrete cone.

According to (Kankam 2000), the high water absorption of palm kernel shells resulted in a lower workability of the constituent concrete since the percentage water absorption of palm kernel shell and crushed rock was found to be 20.5% and 1.04% respectively. Therefore concrete with palm kernel shell aggregate would be expected to require more water during mixing compared with natural rock aggregate while for the compressive strength, it was evident that for both types of aggregate the compressive strength of palm kernel shell concrete shows an approximate uniform reduction in compressive strength for all mixes considered.

The work of (Alex 2015) on "The shear strength properties of structural lightweight reinforced concrete beams and two-way slabs using palm kernel shell coarse aggregate" revealed that the physical and mechanical properties of the PKS aggregate are satisfactory, based on (BS 882). Mechanical properties such as aggregate crushing, aggregate impact and Los Angeles abrasion values are found to be lower than corresponding values for the granite aggregates. PKS aggregates possessed high abrasion resistance which suggested that PKS aggregates can be used as a floor finish, especially in areas of high pedestrian traffic. PKS aggregates have high water absorption (about 18%) compared to only 0.68% for granite aggregates. This can adversely affect the workability of the PKS concrete at the mixing stage with subsequent effect on the hydration of the cement and the creation of voids in finished concrete and based on the physical properties of PKS aggregate, PKS is a potential construction material and can be used as a complete replacement of granite aggregates for low applied load situations. Its use in construction also solves the environmental problem of disposal of the agriculture waste material.

It was observed that PKS aggregate concrete can be used to produce structural concrete with compressive strength of to 24.87N/mm2 using Ordinary Portland Cement (OPC) without the use of superplasticizers. The minimum cement content required was 500 Kg/m3 with water/cement ratio of 0.4. Additionally, PKS can be used with Portland-limestone cement to produce Lightweight Concrete with compressive strengths up to 18.56N/mm2 without the use of superplasticizers. The required minimum cement content is 500kg/m3 with water/cement ratio of 0.4. To achieve a 28-day compressive strength of 27.47N/mm2 with OPC, a mix proportion containing PKS as coarse aggregate has been determined. The minimum cement content required is 500kg/m3, water/cement ratio of 0.38 and superplasticizer content of 1% of the weight of the cement. Similarly, a 28-day compressive strength of 24.86N/mm2 has been produced using Portland-limestone cement with minimum cement content of 500kg/m3, water/cement ratio of 0.38 and superplasticizer content of 1% of the weight of the cement, and It was also revealed that PKS aggregates can be used to produce concretes with compressive strength higher than the minimum required strength of 17N/mm2 for structural Light Weight Concrete as given by the (ASTM C330). The results of the study showed that Palm Kernel Shell has a good potential as a coarse aggregate for the production of structural Light Weight Concrete, especially where high strength is not of major objective in construction.

(Ndoke 2006) Also investigated the performance of palm kernel shell as a partial replacement of coarse aggregate in asphalt concrete. He observed that palm kernel shell can be used to replace coarse aggregate up to 30% before drastic reduction in strength becomes noticeable. He therefore recommended that for heavily trafficked roads, palm kernel shells up to 10% can be used for the replacement while even 100% replacement is possible for lightly trafficked roads in rural settings.

He concluded that:

i. For the very lightly trafficked roads in the rural communities palm kernel shells can be used as full replacement for the coarse aggregate. This will go a long way into reducing construction and maintenance costs of these needs.
ii. The economic power of the rural dwellers will be enhanced, if they are encouraged to plant palm trees from where these shells could be gotten.

(Ndoke 2006) In his experimental study of Palm Kernel shell as a dust control palliative on an unpaved road reported that palm kernel shells were able to reduce the quantity of dust generated from the road to about 75% a few days after the application. It was then suggested that with the absence of funds for road maintenance works organic materials like palm kernel shells could be used as palliatives. He suggested that;

i. Palm kernel shells could be used as a dust control palliative as this will reduce the quantity of dust generated from the road surface.
ii. The use of the shells will go a long way in reducing impact of dust on dust-sensitive vegetation, vehicular action, respiratory problems, complaint from public road users and sedimentation in water bodies.

iii. Immediate application of palm kernel shells reduced the dust produced from the road at some speeds to zero. The rate of preservation of materials was between 75% and 100%.

iv. Daily monitoring of the effectiveness of the palm kernel shells showed that vehicular compactive action which led to the embedding of some of the shells exposed the surface which released some more dust. More shells should be placed on the exposed surface.

v. With the paucity of funds in develop

In the University of Malaysia located at Sabah a small foot bridge of about 2m in span was constructed in May 2001 with oil palm shell as shown in Figure 2.1. In year 2003 a low cost house with floor area of about $59m^2$ was also built using OPS oil palm shell as shown in Figure 2.2 (Teo *et al.*, 2006).

Also, in Federal University Oye-Ekiti (Ikole Campus) at the school hostel a culvert of span 1.3m was constructed partially replacing granite with PKS aggregate as shown in Plate 2.1.

Figure 2.1: A foot bridge made from oil palm shell (Teo *et al.*, 2006).

Figure 2.2: A low cost house from oil palm shell (Teo *et al.,* 2006)

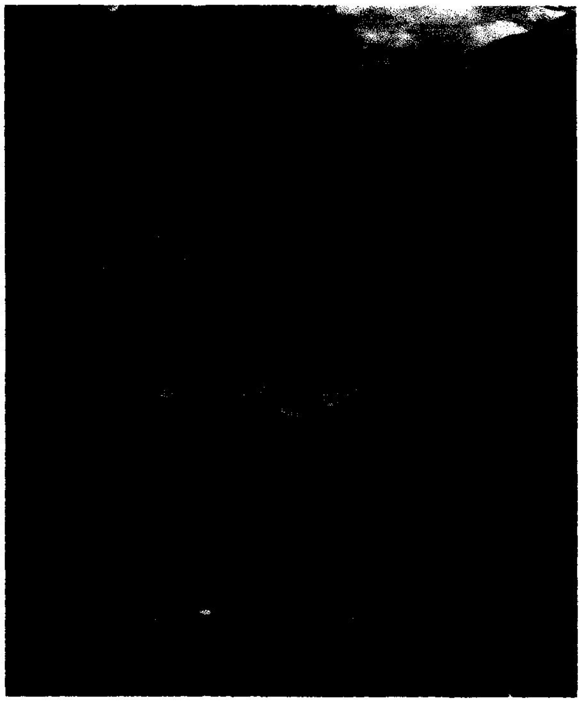

Plate 2.1: A culvert with PKS aggregate

2.0 Light Weight Concrete

(Owens 1993) Stated that usually aggregate which have dry weights (of less than) 1200kg/m^3 are classified as light weight aggregates. Palm kernel shell aggregate has a unit weight of 500 – 650kg/m^3 and this is approximately 60% lighter compared to the conventional crushed stone aggregate. Consequently, the resulting concrete will be light weight.

Light weight concrete is a type of concrete with aggregates of low specific gravity or high porosity which result in a lessened dead weight of the structure (Alex 2015). The density of normal concrete ranges from 2200 - 2600 kg/m^3 while that of light weight is within 300 - 2000 kg/m^3. Substantial economy is achieved on material (concrete, steel) when lightweight concrete is used in high dead load/total load situations. According to (Shetty 2005) there are many advantages of having low density, such as;

i. Reduction in dead load
ii. Heat insulation capacity
iii. Reduction in the use of resources
iv. Lower haulage and handling cost
v. Quicker production potential

(Short and Kinniburgh 1978) and (Bhatty and Reid 1989), classified light weight concrete according to density, into three groups. They are low density concrete commonly used in heat isolations, middle density concretes which are used for briquette producing and the carrier light weight concrete have the opportunities to be used for construction of foundations and supporting parts.

According to (Gupta and Gupta 2004) workability of light weight aggregate concrete needs special attention, as for equal workability light weight aggregate concrete gives a lower slump and a lower compacting factor than the normal weight aggregate concrete as work done by gravity is smaller in case of light weight aggregate concrete. He further said that if a higher workability is kept, there will be a higher tendency of segregation. In case of higher slump and over vibrations, the mortar goes down and aggregate tends to float, which is a reverse phenomenon that of normal weight aggregate concrete. In such conditions the finishing operations of deck slab and floors will be difficult.

(Afolayan 2015) Enumerated the following as the important characteristics of light weight concrete:

i. Fire resistance. The fire resistance properties of light weight concrete are excellent. Its low thermal conductivity makes it suitable for the protection of other structures from the effect of fire.

ii. Speed of construction. By adopting prefabrication of units, the structure can be designed on the concept of modular coordination, which ensures a faster rate of construction.

iii. Durability. Aerated concrete is slightly alkaline. Due to its porosity and low alkalinity it does not provide any protection to the steel reinforcement as provided by the dense compacted concrete. Thus the reinforcement used in cellular concrete needs special treatment for the protection against corrosion.

iv. Economy. Due to the high ratio of strength to mass and light weight of cellular concrete products, their use results in lesser consumption of steel. Composite floor construction using precast unreinforced cellular concrete blocks and reinforced concrete grid beams results in appreciable saving in the consumption of cement and steel. This reduces the cost of construction of roofs and floors considerably. Using this type of construction a saving of about 15-20% can be effected in the construction of roofs and floors in comparison to conventional construction.

v. Thermal insulation. The insulation value of light weight concrete is about 3 to 4 times more than that of bricks and about 10 times that of concrete. The degree of insulation of 20 cm thick wall of aerated concrete of density of 800 kg/m3 is the same as that of 40 cm thick brick wall of 1600 kg/m3 density.

vi. Low density. The density of this concrete varies from 300 to 1200 kg/m3. The lightest variety is suitable for insulation purposes while the heavier variety is used for structural purposes. The low density of cellular concrete makes it suitable for pre-cast roofing and floor units. These units being lighter are easy to handle and transport from factory to the site.

vii. High strength. The compressive strength of cellular concrete is high in relation to its density. The compressive strength of such concrete has been found to increase with the increase in its density. The tensile strength of cellular concrete is about 15 to 20% of its compressive strength. The strength to mass ratio of cellular concrete is much higher than normal concrete. Thus the weight of roof slab and floor of the cellular concrete arc about 25% of the normal reinforced concrete.

viii. Shrinkage. The shrinkage of light weight concrete is small. The autoclaving of cellular concrete reduces its dry shrinkage to 20% of that occurring during air curing.

2.1 Aggregates

Aggregates are the important constituent in concrete, they are inert solid bodies such as gravel textured rocks and sand-like materials. Aggregates come in different sizes and textures: coarse, fine or very fine. Most aggregates come from nature: crushed rock or gravel for coarse aggregates; natural sand or finely crushed rocks for fine aggregates. (Concrete Technology 2015)

Aggregates are graded by passing it through a set of sieves with progressively smaller mesh sizes. All material that passes through sieve #4 [0.187 in. (4.75 mm) openings] is conventionally referred to as fine aggregate or sand, while all material that is retained on the #4 sieve is referred to as coarse aggregate, gravel, or stone. The aggregate constitutes typically 70% - 80% of the concrete volume and therefore, its properties largely determine the properties of the concrete. For the concrete to be of good quality, the aggregate has to be strong and durable and free of silts, organic matter, oils, and sugars. Otherwise, it should be washed prior to use, because any of these impurities may slow or prevent the cement from hydrating or reduce the bond between the cement paste and the aggregate particles (Alex 2015).

It may be mentioned that many properties of aggregates namely, chemical and mineral composition, petro-graphic description, specific gravity, hardness, strength, physical and chemical stability pore structure etc. depend mostly on the quality of the parent rock. But there are some properties possessed by the aggregates which are important so far as concrete making is concerned which have no relation with the parent rock, particularly, the shape and size. While it is to be admitted that good aggregates from good parent rocks can make good concrete, it may be wrong to conclude that good concrete cannot be made from slightly inferior aggregates obtained from not so good parent rocks. Aggregates which are not so good can be used for making satisfactory concrete owing to the fact that coating of cement paste on aggregates bring about improvement in respect of durability and strength characteristics. Therefore selection of aggregates is required to be done judiciously taking the economic factor in consideration. Several factors may be considered in making the final selection of aggregates where more than one source is available (Concrete Technology 2015).

2.2 Classification of Aggregates

Aggregates can be classified in several different ways: whether they are natural or manufactured; whether they are crushed or naturally processed; whether they are inert or reactive; based on their specific gravity; and based on the sizes of their particles. Based on the specific gravities, three categories as normal weight aggregates, lightweight aggregates, and heavyweight aggregates (Figure 2.3) can be produced (Alex 2015). On the basis of size, one can distinguish between fine aggregates, consisting mostly of small materials passing No. 4 sieve (3/16 in.) and retained on No. 200 sieve and coarse aggregates, mostly consists of large particles retained on the 4.75-mm (No.4) sieve (ASTM C125-07, 2007)

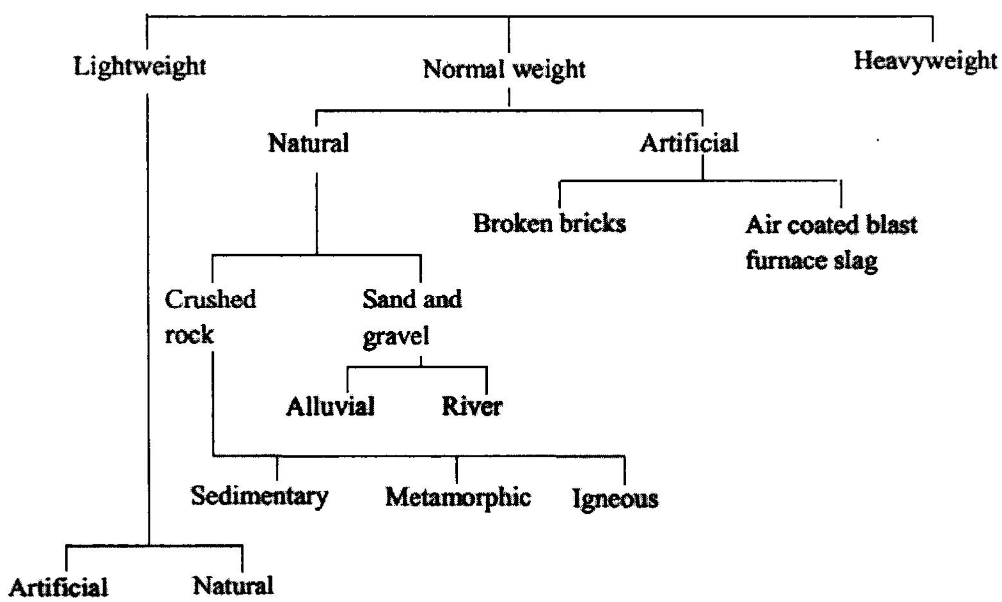

Figure 2.3: Classification of aggregates (Neville and Brooks 2008)

2.2.0 Classification of Aggregate According in Source

Almost all natural aggregate material originate from bed rocks. There are three kinds of rocks, namely, igneous, sedimentary and metamorphic. These classifications are based on the mode of formation of the rocks. It can be recalled that igneous rocks are formed by the cooling of molten magma or lava at the surface of the crest (trap and basalt) or deep beneath the crest (granite). The sedimentary rocks are formed originally below the sea bed and subsequently lifted up. Metamorphic rocks are originally either igneous or sedimentary rocks which are subsequently metamorphosed due to extreme heat and pressure. The concrete making properties of aggregate are influenced to some extent on the basis of geological formation of the parent rocks together with the subsequent processes of weathering and alteration (Concrete Technology 2015).

2.2.0.0 Aggregates from Igneous Rocks

Igneous rock is one the widely occurring type of rocks on the face of the earth, bulk of concrete aggregates that are derived, are of igneous origin. Most igneous rocks make highly satisfactory concrete aggregates because they are normally hard, tough, and dense. The igneous rock as a class are the most chemically active concrete aggregate and show a tendency to react with alkalis in cement (Concrete Technology 2015)

2.2.0.1 Aggregates from sedimentary rocks

Igneous rocks or metamorphic rocks are subjected to weathering agencies such as sun, rain wind. These weathering agencies decompose, fragmentise, transport and deposit the particles of rock, deep beneath the ocean bed where they are cemented together by some of the cementing materials. The deposition, cementation and consolidation takes place layer by layer beneath the ocean bed. These sedimentary rock formations subsequently get lifted up and becomes continent (Concrete Technology 2015) .The sedimentary rocks with the stratified structure are quarried and concrete aggregates are derived from it. The quality of aggregates derived from sedimentary rock vary in quality depending on the cementing material and the pressure under which these rocks are originally compacted. Some siliceous sand stones have proved to be good concrete aggregates. The stratification thickness affects the strength of the aggregate. If the stratification thickness is less it may yield flaky aggregates. Sedimentary rocks vary from soft to hard, porous to dense and light to heavy. The degree of consolidation, the type of cementation, the thickness of layers and contamination, are all important factors in determining the suitability of sedimentary rock for concrete aggregate (Concrete Technology 2015).

2.2.0.2 Aggregates from metamorphic rocks

Both igneous rocks and sedimentary rocks may be subjected to high temperature and pressure which causes metamorphism which changes the structure and the texture of rocks. Metamorphic rocks show foliated structure. The thickness of this foliation may vary from a few centimetres to many meters. If the thickness of this foliation is less, then individual aggregates may exhibit foliation which is not a desirable characteristic in aggregate. However, many metamorphic rocks particularly quartizite and gneiss have been used for the production of good concrete aggregates (Concrete Technology 2015).

2.2.1 Classification of aggregate according to size

Concrete is produced with coarse aggregates that range from 5 mm to 50 mm size with 20 mm being very common. The grading of an aggregate is defined as the frequency of distribution of the particle sizes of a particular aggregate. Particle size distribution significantly affects some properties of concrete like packing density and voids contents. Consequently, the workability, segregation, durability and some other characteristics of concrete are greatly affected (Karthik *et al.*, 2007).

Past researchers have it that uniformly distributed mixtures produce better workability than gap-graded mixtures (Golterman *et al.*, 1997), and is desirable for the efficient utilization of the matrix. Uniformly distributed aggregates lead to higher packing, which result in concrete with higher density and less permeability (Golterman *et al.*, 1997), and improved abrasion resistance (Mehta and Monteiro 1993).

According to (Quiroga and Fowler 2004), size distribution divides aggregates in three categories as coarse aggregates, fine aggregates and micro-fines. Excessive coarse aggregate can produce concrete with poor abrasion resistance while excessive sand can produce mixes requiring increased water for effective finishing. Smaller nominal maximum size of aggregate has a larger surface area compared to larger nominal size of aggregates. This results in a high bonding strength at the interface zone around the smaller aggregate particles when concrete is under loading (Neville 1997).

(Yaqub and Bukhari 2006) Studied the effect of size of coarse aggregate on compressive strength of high strength concrete. The study concluded that aggregate sizes of 10mm and 5mm showed higher strength than all other sizes of aggregates.

Figure 2.4, taken from (Neville and Brooks 2008), shows a relationship between the maximum sizes of aggregate on the 28-day compressive strength of concrete of different richness.

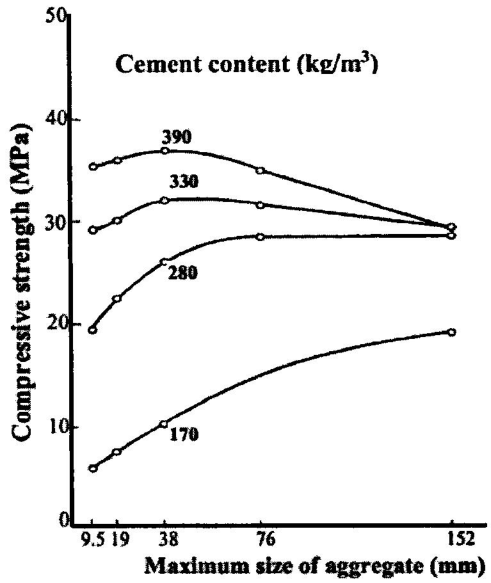

Figure 2.4: Influence of maximum size of aggregate on the 28-day compressive strength of concretes of different grades (Neville and Brooks, 2008)

2.2.2 Classification of aggregate according to shape

Shape refers to the geometry of the aggregate. Shape is related to sphericity, form, angularity, and roundness. The shape of aggregate particles influences paste demand, placement characteristics such as workability, strength, void content, packing density and cost. (Rached *et al.,* 2009). From the standpoint of economy in cement requirement for a given Water/cement ratio, rounded aggregates are preferable to angular aggregates. On the other hand, the additional cement required for angular aggregate is offset to some extent by the higher strengths and sometimes by greater durability as a result of the interlocking texture of the hardened concrete and higher bond characteristics between aggregate and cement paste (Concrete Technology 2015).

Two important aspects of shape which are desirable for concrete production are roundness and sphericity. While the roundness describes the relative sharpness of the edges and corners of a particle (Quiroga and Fowler 2004), the sphericity measures the ratio of the surface area of the particle to its volume. A broad classification of shapes of coarse and fine aggregates are given in Table 2.1. Figure 2.5 and Figure 2.6 provides two comparable charts for visual assessment of particle shape.

Table 2.1: Classification of Particle Shapes of Aggregates (Neville and Brooks, 2008)

CLASSIFICATION	DESCRIPTION
Rounded	Fully water-worn or completely shaped by wearing
Irregular	Naturally irregular or partly shaped by attrition and having rounded edges
Flacky	Materials of small thickness relative to the other two dimensions
Angular	Possessing well-defined edges formed at the intersection of roughly planar faces
Elongated	Materials in which the length is considerably larger than the other two dimensions
Flaky and Elongated	Materials having the length considerably larger than the width and the width considerably larger than the thickness.

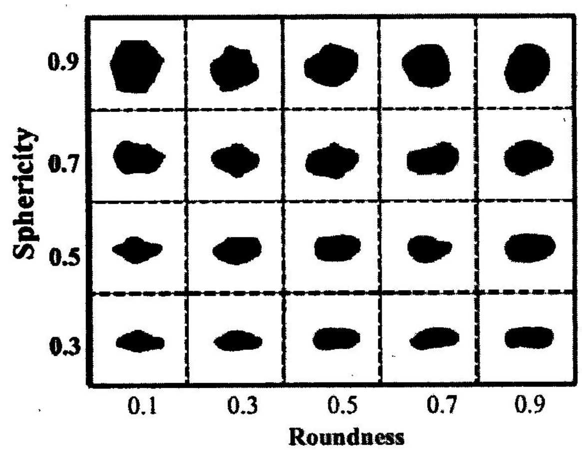

Figure 2.5: Visual assessment of particle shape derived from measurement of sphericity and roundness (Quiroga and Fowler, 2004)

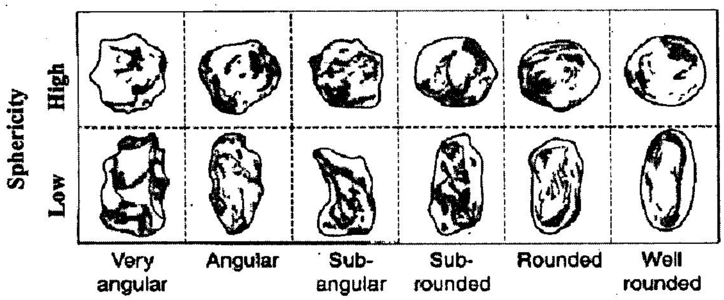

Figure 2.6: Visual assessment of particle shape based on morphological observations (Quiroga and Fowler, 2004)

A lot has been said on whether the angular aggregate or rounded aggregate will make better concrete. Angular aggregate are superior to rounded aggregates from the following two points of view (Concrete Technology 2015);

i. Angular aggregates exhibit a better interlocking effect in concrete, which property makes it superior in concrete used for roads and pavements.
ii. The total surface area of rough textured angular aggregate is more than smooth rounded aggregate for the given volume. By having greater surface area, the angular aggregate may show higher bond strength than rounded aggregates.

The higher surface area of angular aggregates with rough texture requires more water for a given workability than rounded aggregates. This means that for a given set of conditions from the point of view of water/cement ratio and the consequent strength, rounded aggregates gives higher strength. Superimposing plus and minus points in favour and against these two kinds of aggregates it was concluded that, for water/cement ratio below 0.4 the use of crushed aggregates resulted in strength up to 38 per cent higher than the rounded aggregate. With an increase in water/cement ratio the influence of roughness of surface of the aggregate reduced, presumably because the strength of the paste itself becomes paramount, and at a water/cement ratio of 0.65, no difference in strength of concrete made with angular aggregate or rounded aggregate was observed (Concrete Technology 2015).

2.2.3 Classification of aggregate according to texture

(Graves 2006) Defines surface texture of an aggregate as the degree to which the surface may be either rough or smooth, or coarse grained or fine grained. Surface texture depends on hardness, grain size, pore structure, structure of the rock, and the degree to which forces acting on the particle surface have smoothened or roughened it (Concrete Technology 2015). Surface texture characteristics of the aggregate as classified in (IS:383:1970) is shown in Table 2.2.

Table 2.2: Surface Characteristics of Aggregate (Concrete Technology, 2015).

GROUP	SURFACE TEXTURE	EXAMPLES
1	Glassy	Black flint
2	Smooth	Chert; slate; marble; some rhyolite
3	Granular	Sandstone; oolites
4	Crystalline	Fine: basalt; trachyte; Medium: Dolerite: granophyre; granulite; microgranite; some limestone Coarse: gabbro; gneiss; granite; granodiorite; syenite
5	Honeycombed and porous	Scoria; pumice; trass

2.2.4 Flakiness and elongation indices

According to (Legg 1998), flaky and elongated particles tend to produce harsh mixes and affect the extent to which concrete products can be finished. Flaky and elongated aggregates, principally those of intermediate sizes (9.5mm and 2.36 mm), can affect the mobility of aggregates and contributes to harshness (Shilstone 1990). Excessive use of poorly shaped particles reduces the strength of concrete through increase in water demand. During concrete production, water accumulates below elongated and flaky particles which reduce the bond between the paste and the aggregates in general (Shetty 2005). Flakiness and elongation influence aggregate gradation, reduces interlocking characteristics, and some specifications limit the amount of flaky and elongated particles (Quiroga and Fowler 2004).

2.2.5 Aggregate moisture content

Moisture content is the water contained in an aggregate in excess of saturated and surface dry conditions. Since aggregates contain some voids, it is possible for water to be absorbed into the particle. Additionally, water can be retained on the surface of the particle as a film of moisture.

2.2.6 Porosity and water absorption of aggregate

Some of the aggregates are porous and absorptive. Porosity and absorption of aggregate will affect the water/cement ratio and hence the workability of concrete. The porosity of aggregate will also affect the durability of concrete when the concrete is subjected to freezing and thawing and also when the concrete is subjected to chemically aggressive liquids (Concrete Technology 2015). Water absorption of an aggregate is the increase in the weight of the aggregate due to water being absorbed into the pores of the material during a prescribed time, but not including the water adhered to the surface of the aggregate. The rate and total amount of water absorption depends on the pore volume, structure of the pore (whether connected or disconnected), pore distribution, characteristic of particle surface, and the initial moisture content (Kayali and Haque 1999).

In proportioning the materials for concrete, it is always taken for granted that the aggregates are saturated and surface dry. In the mix design calculation the relative weight of the aggregates are based on the condition that the aggregates are saturated and surface dry but in practice, aggregates in such ideal condition is rarely met with. Aggregates are either dry and absorptive to various degrees or they have surface moisture. The aggregates may have been exposed to rain or may have been exposed to the sun for a long time in which case they absorptive (Concrete Technology 2015).

2.3 Laterite

According to (Makasa 1998) the soil name "Laterite" was given by Buchanan (1807) in India, from a Latin word "later" meaning brick. Laterite is used extensively in the construction of embankments for roads and earth dams. Lateritic soils, according to (Osadebe and Nwakonobi 2007) are widely used as construction material in Nigeria and other under-developed and developing countries of the world. However, they argue that laterites have not been extensively used in constructing medium to large-size building structures, probably because of lack of adequate data needed in the analysis and design of structures built of lateritic soils. This underscores the need for more research efforts in this area. According to (Adoga 2008), Laterite is a highly weathered material rich in secondary oxides of Iron, Aluminum or both. It is nearly devoid of base and primary silicates but may contain large amount of quarts, and Kaolinite. Laterite has been used for wall construction around the world; it is cheap, environmentally friendly and abundantly available building material in the tropical region (Olugbenga *et al.,* 2007) reported that approximately 30% of the world's present population still lives in lateritic structures. They observed that the restriction of laterite building to rural areas is due to lack of accepted standard design parameters for the effective structural applications of laterized concrete. They described Terracrete as a mixture of laterite (as fine aggregate), granite or gravel (coarse aggregate), cement and water in a chosen weight proportion, mixed by means that are available and equally allowed to undergo curing processes

USE OF LATERITE

Lateritic soils are widely used as a construction material in Ghana and other developing countries of the world. In addition to mud walls, brick masonry (dried or burnt type) are made from lateritic soils in rural areas of the country. Research has shown that laterite can be used to replace sand component of concrete either wholly or partially and is becoming widespread among the low income earners for building construction. The utilization of laterites enables the provision of low-cost houses and other rural infrastructures. That notwithstanding, their extent of utilization is very low. This is probably due to lack of adequate data needed in the design of structures using this material. Lateritic soil has been one of the major building materials (Osadebe and Nwakonobi 2007).

2.4 Laterized Concrete

Laterized concrete is defined as concrete in which stable laterite fine replace aggregate (Sand). In a research by (Adepegba 1977), he compared resistance to high temperature, modulus of elasticity and compressive and tensile strength of laterized concrete mixes (1:2:4; 1:1.5:3 and 1:1:2 by weight) with that of normal concrete. He concluded that for high strength and workability only 25% of sand in concrete should be substituted with lateritic fine, while the mix ratio should be 1:1.5:3 (cement: sand/laterite: granite) with a water/cement ratio of 0.65. According to (Osunade 2002), laterized concrete is concrete in which the fine aggregates are lateritic soils. Laterite is a mixture of clayey iron and aluminum oxides and hydroxides formed as a result of the weathering of basalt under humid, tropical conditions. It is readily available in all parts of Nigeria. The quest of having concrete which is cheaper has prompted many researchers to work on laterized concrete. Different properties of laterized concrete have been considered at different stages with far reaching recommendations in favour of laterite as suitable for use in the construction industry. Working on shrinkage deformations of laterized concrete, (Salau and Balogun 1998) recommended that laterized concrete with up to 25% laterite content of the aggregate could be used in load-bearing structural elements. It was also found out in another work by (Balogun and Adepegba 1982) that the most suitable mix for structural application of laterized concrete was 1:1.5:3 with about 0.65 water/cement ratio provided that the percentage of laterite content was kept below 50%. They asserted also that compressive strength of not less than 25N/mm2 was obtained at 28days for the mix with laterite content of about 25 - 50%. A combination of crushed granite, sharp sand and fine laterite was used in their experiment (Lasisi and Osunade 1985) listed mix proportion, water/cement ratio, curing ages, grain size ranges, stress level, laterite soils- river sand variation as some of the factors that affect the strength and creep properties of laterized concrete. They observed that increase in cement content and decrease in water/cement ratio results in increase in the compressive strength of laterized concrete. According to (Lasisi and Osunade 1985), the creep of laterized concrete, unlike that of conventional concrete which showed some definite recovery after unloading, did not show any form of recovery. (Lasisi and Ogunjide 1984) Also established that the higher the laterite/cement ratio, the lesser the compressive strength, and the fewer the grain size range, the higher the compressive strength. (Udoeyo *et al.,* 2006) Had also agreed with other researchers that with up to 40% replacement level of sand by laterite, laterized concrete attained the strength of 20N/mm2. They recommended laterized concrete for the construction of buildings and rural infrastructures. Laterized concrete has also been found to have similarity with conventional concrete in some properties: (Falade 1994) found that the already established variations in workability and compressive strength of normal concrete with water/cement ratios are valid for laterized concrete. (Salau and Balogun 1998) Observed in his paper "Long-term deformations of laterized concrete short columns" that there were not many variations between the creep deformations of laterized concrete and normal concrete short columns. He further recommended 25% laterite content of the aggregate for long-term resistance and usage in load-bearing short column members. (Efe and Salaü 2010) Showed that normal concrete cannot withstand appreciable load above 250°C while laterized concrete with 25% laterite in the fine aggregate is able to resist higher load with increase in age and at temperature up to 500°C. They achieved compressive strength of up to 30.44N/mm2 for laterized concrete with 25% laterite and 75% sand at 500°C. Laterized concrete according (Efe and Salau 2010) can be classified as normal weight concrete as the density of all test specimens of 28-day curing age exceeds 2000Kg/m3. They also observed that there is economic saving if laterized concrete is used in areas of high temperature up to 500°C. This differs from the findings of (Udoeyo *et al.,* 2010) that the strengths of laterized concrete and normal concrete decreased in a similar manner when subjected to elevated temperatures of between 200°C and 600°C. (Udoeyo *et al.,* 2010) also found that the workability of laterized concrete increases with laterite content with slump values ranging from 2 - 20mm, while the water absorption showed a reverse trend, that is, decrease with increase in laterite content. Also (Adepegba 1977) recommended 0.65 water/cement ratio as suitable for normal workability.

2.5 Palm Kernel Shell Concrete

The oil palm tree is a monocotyledon belonging to the genus Elaeis. It is one of the important economic crops in the tropics (Anyawu *et al.,* 1982). It belongs to the family Palmae (having 225 genera with over 2600 species), and the sub family Cocoideae of which it is the most important member (Opeke 1987). The oil palm is a versatile tree crop with almost parts of the tree being useful and of economic value. The principal product of oil palm is the palm fruit, which is processed to obtain three commercial products. These include palm oil, palm kernel oil and palm kernel cake. The uses of palm oil are many and varied (Adegbola et. al., 1979). The palm crop has two distinct parts: the fleshy Mesocarp which produces palm oil, and the kernel which produces palm kernel oil (Figure 2.7). According to (Sundram *et al.,*2003) the genus Elaeis comprises two species, namely Elaeis Guineensis (E. Guineensis) and Elaeis Oleifera (E.Oleifera). The E. Guineensis originates from West Africa whilst E.

Oleifera is a stumpy plant of South American origin. Following the preceding background, the oil palm trees in Nigeria are derived from the Elaeis Guineensis specie. It is mostly found in the southern part of Nigeria.

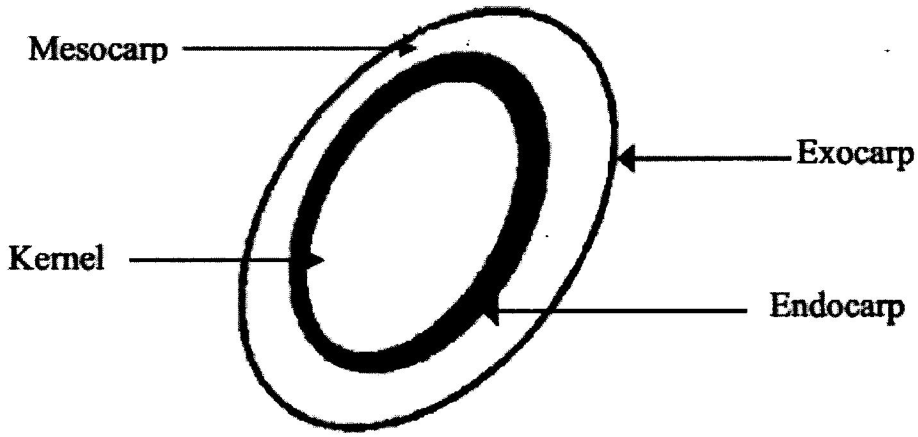

Figure 2.7: Layers of the palm fruit (Adzimah and Seckley, 2009)

2.6.0 Makeup of palm kernel shell (PKS)

PKS are hard endocarps of the palm kernel fruit that surround the palm seeds. During palm oil processing, six stages can clearly be identified: sterilization, threshing, pressing, separation of kernel and shell and clarification (Abdullah 1996). Shells are one of the wastes produced during this process, their colour ranges from dark grey to black. The shells are of different shapes such as curved, flaky, angular, polygonal, elongated, roughly parabolic, and other irregular shapes, depending on the breaking pattern of the nut. (Teo *et al.,* 2006). The surfaces of the shells are fairly smooth for both concave and convex faces with rough and spiky broken edges (Shafigh *et al.,* 2010)

PKS are hard in nature and do not deteriorate easily when used for concrete and therefore, does not contaminate or leach to produce toxic substances (Basri *et al.,* 1999). Thickness varies and depends on the specie of palm tree from which the palm nut is obtained and ranges from 0.15 – 8mm (Teo *et al.,* 2006).

PKS possess similar characteristics as coarse aggregates which encourage their use as replacement for conventional granite aggregates. PKS aggregate has a unit weight of between 500 and 620 kg/m3 (Teo *et al.,* 2006) and this is approximately 60% lighter than conventional granite aggregates. The shell has a porosity of 37% with loose and compacted bulk densities of 545 and 595 kg/m3 respectively (Mannan and Ganapathy 2001). This implies that the material is within the range of bulk densities for lightweight aggregate (300 to 1100 kg/m3) (Neville and Brooks 2008).

The densities of fresh PKS concrete are found to be in the range of 1753–1763 kg/m3 (Okafor 1988) depending on the mix proportions.

2.6.1 Chemical composition of palm kernel shell

(Teo D. *et al.,* 2007) Found in their study that PKS are chemically made of Nitrogen, Sulphur, Calcium (as CaO), Magnesium (as MgO), Sodium (as Na_2O), Potassium (as K_2O), Aluminium (as Al_2O_3), Iron (as Fe_2O_3), Silica (as SiO_2) and Chloride (as Cl^-), of all the chemical components of the shells, sulphur is a threat to the durability of PKS concrete. The attack of sulphuric acid of hydrated Portland cement could cause crack formation and disintegration of concrete. Table 2.3 shows the chemical composition of OPS. From the table, it can be observed that the loss on ignition of OPS is about 100%. This percentage was reported elsewhere (Mannan and Ganapathy 2002).

Table 2.3: Chemical composition of OPS aggregate (Teo *et al.,* 2007)

Elements	Results
Ash	1.53
Nitrogen (as N)	0.41
Sulphur (as S)	0.000783
Calcium (as CaO)	0.0765
Magnesium (as MgO)	0.0352
Sodium (as Na_2O)	0.00156
Potassium (as K_2O)	0.00042
Aluminium (as Al_2O_3)	0.130
Iron (as Fe_2O_3)	0.0333
Silica (as SiO_2)	0.0146
Chloride (as Cl^-)	0.00072
Loss on ignition	98.5

Given the relatively small quantity of sulphur in the PKS (about 0.00783%) (D. Teo, et al. 2007), its effect on hydrated cement is insignificant. It is noted by (Zayed *et al.,* 2004) that a sulphur trioxide content beyond 3% increases drying shrinkage and strength loss for mortar. Given the relatively small quantity of sulphur in the shells, it could be concluded that the presence of the sulphur will have an insignificant effect on the strength properties of PKS concrete. Moreover, the PKS do not contaminate or leach out to produce toxic chemical substances once they are bound in concrete matrix (Basri *et al.,* 1999)

CHAPTER THREE

MATERIALS AND METHODOLOGY

This chapter deals with methods and techniques used in the collection of data as a justification for the suitable approach to the study. Several methods were considered, taken into account the aims and objectives of the research.

3.0 Materials

The materials used for this study are not limited to the following; Ordinary Portland Cement (OPC), laterite, palm kernel shell, granite, sand and water which were all obtained from various places in Ikole, Ekiti State. The PKS aggregate was obtained from a local palm oil production industry according to the quantity provided in material estimate prepared (Appendix A). Granite and sand aggregates were obtained from an on-going construction work close to the university. The laterite aggregate was obtained from a location in the university premise. The cement used was Ordinary Portland Cement which was obtained from the local market.

Plate 3.1: Aggregate materials collected and stored

3.1 Preliminary Investigation

Tests were conducted to assess the mechanical and physical properties of the materials which include palm kernel shell (PKS), granite, sand, and laterite at the soil mechanics laboratory of Federal Polytechnic Ado-Ekiti. The tests conducted include;

3.1.0 Sieve analysis

The sieve analysis also called gradation test, is a basic essential test for all aggregates. The sieve analysis was done according to BS 812: Part103: 1985. It was carried out in the Civil Engineering laboratory of Federal Univeristy Oye-Ekiti (Ikole campus). Sieve analysis was conducted to determine the particle size distribution of aggregate samples. A good gradation alludes that a sample of aggregate contains all the standard fractions. A sample of well graded aggregate containing minimum voids will require minimum paste to fill up the voids in the aggregates. The essence of particle size distribution analysis is to have well graded aggregate which have direct influence on producing workable concrete (Afolayan 2015).

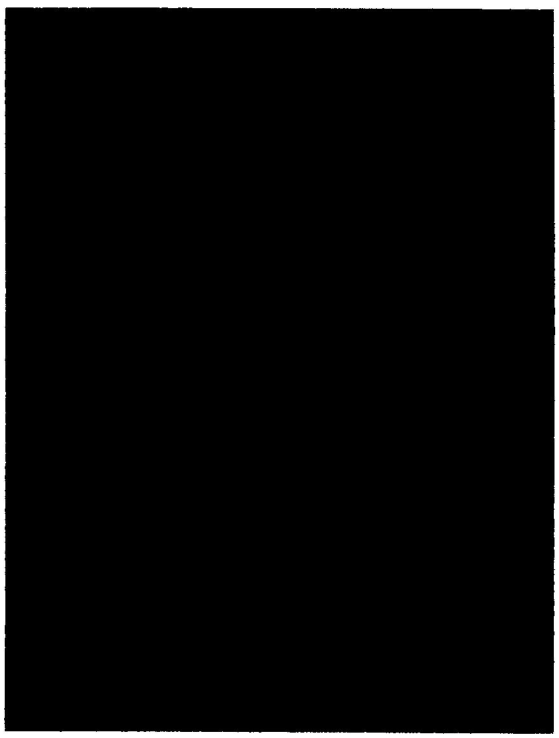

Plate 2.2: Sieve analysis of aggregate samples

3.1.1 Specific gravity

Specific gravity also called **relative density** is the ratio of the density of aggregate to the density of distilled water at a standard temperature. The specific gravity of the aggregate samples were determined in accordance with Indian standard IS 2770: Part3: 1963, Method of test for soil. Pycnometer method for specific gravity was used. The sample was dried in an oven for 16 hours at a temperature of 115°c. The pycnometer was dried and weighed with its cap, and was filled to about two-third with the oven dried specimen and the pycnometer was weighed again. Water was added to cover the specimen and the cap was screwed, entrapped air were removed by shaking the pycnometer. The pycnometer was then filled with water and weighed after air has been removed. The pycnometer was cleaned completely with water and the cap was screwed. The outside of the pycnometer was dried and weighed. The specific gravity was determined from the ratio of the weight of the aggregate to the weight of equal volume of water.

Plate 3.3: Specific gravity test set-up (weighing balance, samples, Pycnometer)

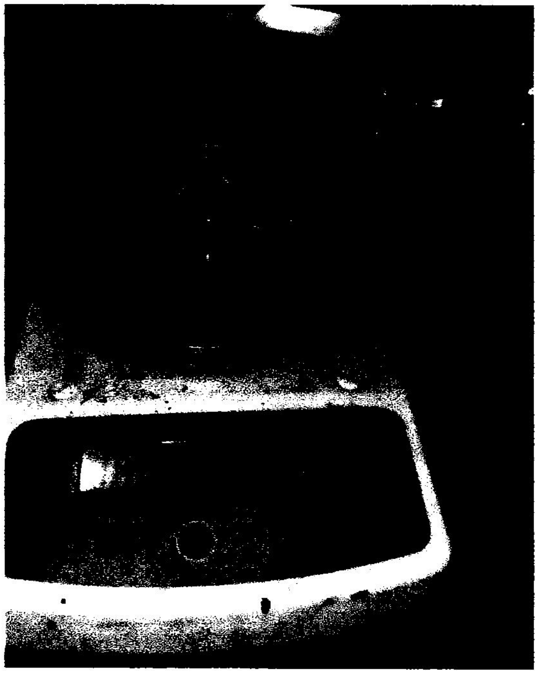

Plate 3.4: Specific gravity test of aggregate samples.

3.1.2 Porosity

Porosity is the ratio of the volume of the pores to the total volume of the particle. The porosity for the PKS, and granite aggregates were determined in accordance with BS 812: Part2: 1995.

A cylindrical container was filled with the aggregate sample to about one-third the container. Then compactive blows were given to the aggregate sample, with each blow been given by allowing the tamping rod to fall freely from 5mm above the surface of the aggregate. Similar quantity of aggregate was added and same number of blows was given. Container was filled till it overflowed and it was tampered with the same number of blows. Excess aggregate was removed by rolling the tamping rod across the top of the container. The mass of the aggregate in the container was determined.

Void was determined as a percentage of the volume of the test cylinder. It was determined from the difference between the volume of the test cylinder and the calculated volume of the aggregate. Percentage of void is the difference between particle density of the aggregate on an oven-dry basis and the bulk density of oven-dry aggregate divided by the bulk density of the oven-dry aggregate.

3.1.3 Moisture content

The moisture content of the aggregate samples were determined in accordance with BS812: Part 109: 1990. The oven drying method (Definitive method) was adopted for the test. The oven-drying method provides a measure of the total water present in a sample of aggregate, the method comprises placing a test portion in a container and heating it in an oven until it reaches constant dry mass. Moisture content is then determined by the difference in mass and expressed as a percentage of dry mass.

A clean container, dried was weighed and aggregate sample was placed in the container and then re-weighed. The container containing the aggregate sample was placed in the oven and was dried at a constant temperature of 105°c. The container was removed from the oven and cooled in an air tight container for one hour and was weighed again. The moisture content was determined as a percentage of the dry mass.

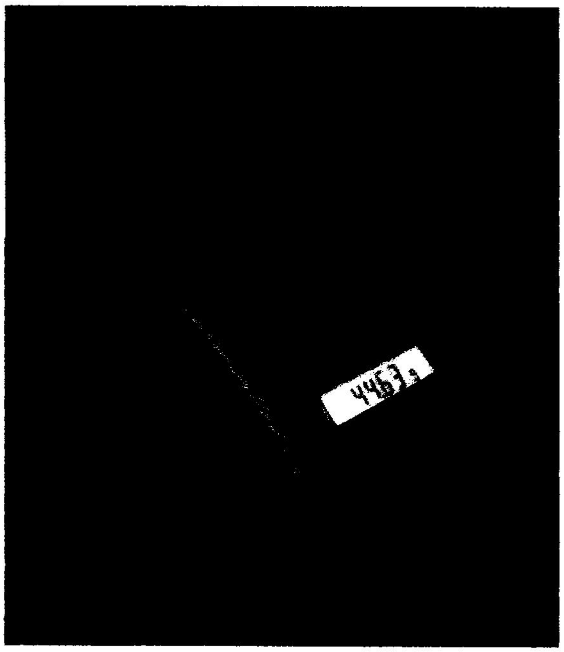

Plate 3.5: Weighing PKS aggregate for moisture content test

Plate 3.6: Drying the aggregate samples in a controllable oven

3.1.4 Loose bulk density

Bulk density is the weight of material in a given volume. It is expressed in kg/m^3. The bulk density (unit weight) of an aggregate gives valuable information regarding the shape and grading of the aggregate. The bulk density was determined in accordance with provisions in BS 812: Part 2: 1995.

A cylindrical container was filled with the aggregate sample to about one-third the container. Then compactive blows were given to the aggregate sample, with each blow been given by allowing the tamping rod to fall freely from 5mm above the surface of the aggregate. Similar quantity of aggregate was added and same number of blows was given. Container was filled till it overflowed and it was tampered with the same number of blows. Excess aggregate was removed by rolling the tamping rod across the top of the container. The mass of the aggregate in the container was determined.

3.1.5 Water absorption

The water absorption of the PKS and granite aggregate were determined in accordance with the recommendation for testing aggregates in BS 812: Part 2: 1995.

The test specimen was immersed in a glass vessel containing water for 24 hours at a temperature of 20°c. After immersion and soaking bubbles and entrapped air are removed from the surface of aggregate by gentle agitation. It was done by the rapid clockwise and anti-clockwise rotation of the vessel.

The vessel was filled with water preventing air from been entrapped in the vessel. The outside of the vessel was dried and weighed.

After 24 hours, the sample was placed on a dry cloth and gently surfaced dried with the cloth. And then weighed to obtain a surface dry weight. The sample was then placed in an oven at a constant temperature of 105°c for 24 hours. Then it was cooled in an air tight container and weighed. The water absorption was determined as the ratio of decrease in mass of the surface dry sample to the mass of the oven dry sample, expressed as a percentage.

3.1.6 Aggregate Crushing Value (ACV)

The ACV of the PKS and granite aggregate was carried out in accordance with provisions in BS 812: Part 110: 1990. The test gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load

Aggregates that passed through the 14mm test sieve and retained on the 10mm test sieve was used for this test. A cylinder of the test apparatus was placed on a base plate and the test specimen was compacted in three layers of approximately equal depth, each layer was subjected to 25 strokes from a tamping rod of cross-section 16mm, distributed evenly over the surface of the layer and dropping from a height approximately 50mm above the surface of the aggregate. The specimen surface was levelled carefully and the plunger was inserted in such a way that it rested horizontally on the surface. The specimen was subjected to a load of 400KN applied through the plunger in 10 minutes. After crushing the specimen was sieved on a 2.36mm test sieve. The aggregate crushing value was determined as a percentage of the mass of fine particles passing the 2.36mm test sieve to the total mass of the test specimen.

Plate 3.7: Aggregate crushing test.

Plate 3.8: Sieving the crushed aggregate with 2.33mm test sieve

3.1.7 Aggregate Abrasion Value (AAV)

Aggregate abrasion test measures resistance of aggregate to surface wear by abrasion. The AAV for the PKS and granite aggregate was determined in accordance with BS 812: Part 113: 1990.

Two specimens from a test portion with their center points opposite to each other were placed in an abrasion machine. Sand, fed by hoppers was used as an abrasive. After 500 disc rotations the amount of material abraded was measured by calculating the weight loss of the aggregate. The aggregate abrasion value was determined by measuring the difference in mass of the aggregates before and after the abrasion. The result was expressed as a percentage by weight of the test sample.

3.1.8 Aggregate Impact Value (AIV)

The AIV of the PKS and granite aggregate was determined in accordance with BS 812: Part112: 1990. The test was performed on aggregates passing the 14mm test sieve and retained on the 10mm test sieve. The aggregate was compacted into an open steel cup of the aggregate test machine in a standardized manner (25 strokes with a tamping rod). The specimen was subjected to a total of 15 blows, each been delivered at an interval of not less than one second, from a height of 380mm above the upper surface of the aggregate in the cup. After the 15th blow the specimen was removed by holding the cup over a clean tray and hammering on the outside with a rubber mallet till particles were sufficiently disturbed to enable the specimen to fall freely on the tray. The specimen in tray was sieved on a 2.36mm test sieve. The aggregate impact value was determined by measuring the ratio of the mass of fine particle passing the 2.36mm test sieve to the total mass of the test specimen expressed as a percentage.

3.2 Main Investigation

3.2.0 Compressive strength and density of concrete

The response of concrete when stress is applied on a hardened concrete depends on the stress type and on various factor which is not limited to properties and proportions of materials that are used for concrete mixture design, degree of compaction and conditions of curing (Jankovic *et al.,* 2011). Strength is usually determined by means of test cylinders made of fresh concrete on the job and tested in compression at various ages. The requirement is a certain strength at an age of 28days or such earlier age as the concrete is to receive its full service load or maximum stress. Additional tests are frequently conducted at earlier ages to obtain advance information on the adequacy of strength development where age-strength relationships have been established for the materials and proportions used (Nevelle 2012).

3.5.1.1 Preparation of test specimen

The mean compressive strength of concrete were determined by testing three

150 × 150 × 150 mm concrete cubes at 7, 14, 21, 28, 60 and 90 days of age according to (BS1881: Part 116 1983). The batching was done by weight using mix ratio 1: 2: 4, with partial replacement of coarse aggregate with palm kernel shell at 0%, 10%, 20%, 30%, 40%, and 50% and replacement of fine aggregate with laterite at 40%. Also the W/C ratio used was 0.5. The cube moulds were cleaned and lubricated before concrete was placed in them to avoid the concrete paste sticking on the moulds which would result in difficulty when the concrete cubes are to be removed. The mould was filled with freshly mixed concrete in three layers and was compacted using a compacting rod (with each layer not compacted less than 35 strokes per layer) to ensure minimum amount of voids. After compaction, the top of the concrete was levelled to obtain a smooth surface, each set of specimens (comprising three 3 cubes) were labelled for identification.

Plate 3.9: Hand mixing the concrete aggregates

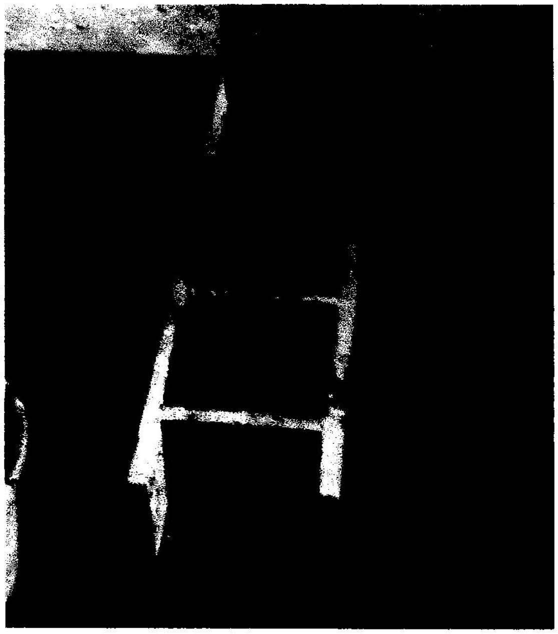

Plate 3.10: Compacting the concrete with compacting rod

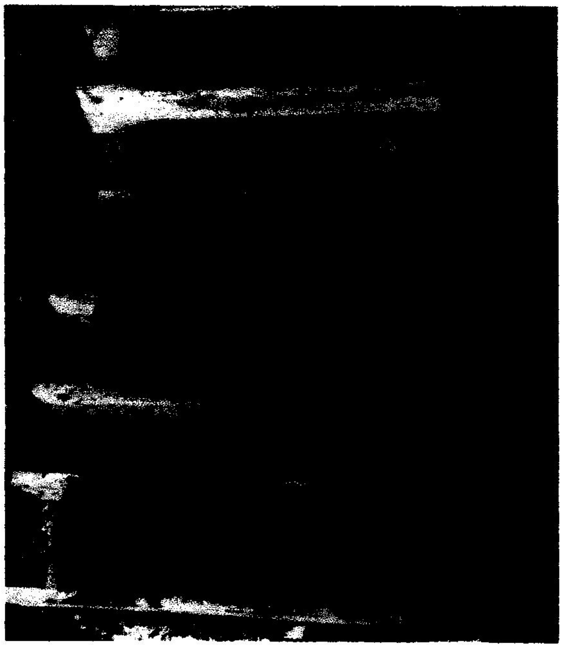

Plate 3.11: Samples of freshly cast concrete cubes

3.5.1.2 Curing of concrete specimen

After casting, the concrete cube specimen were covered with red gunny bag – A damp material to control hydration – for 24 hours. This ensured minimum loss of moisture from the surface of the concrete during the early stage of curing (Orchard 1979). Specimen were then de-moulded and totally immersed in fresh water in a curing tank to ensure complete hydration. (Zawde 1983) Stated that no part of the process of making a good concrete is more important than through curing. On the testing day, the specimen was removed from the water and excess moisture was wiped from the surfaces of the cube specimens, it was allowed to air dry for 30 minutes prior testing (CIvilolgy 2017)

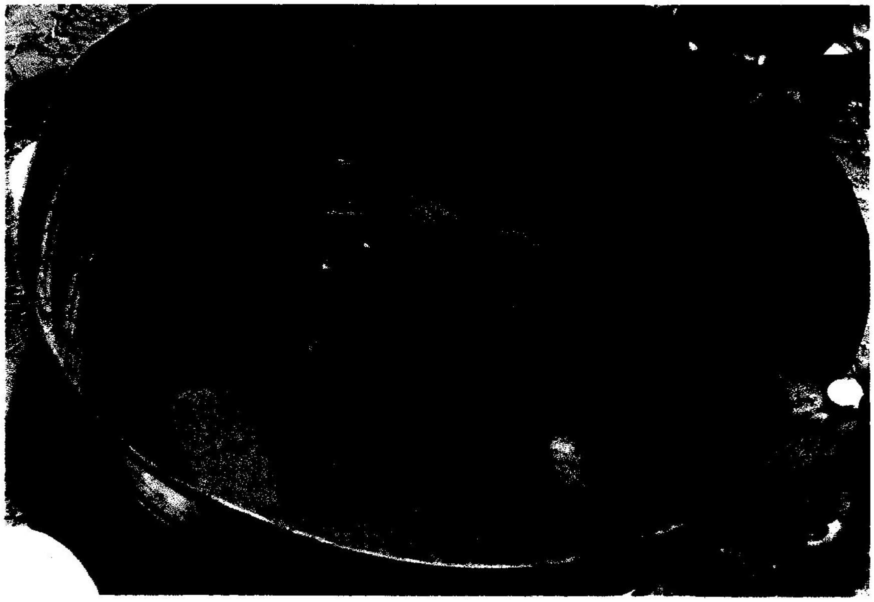

Plate 3.12: Curing the concrete cubes in the curing tank

3.5.1.3 Testing of concrete cubes

Three concrete cubes were tested at each age for each concrete mix. The compressive strength of concrete cube was tested at Civil Engineering laboratory of Afe Babalola University, Ado-ekiti Nigeria, using a universal compression testing machine of maximum capacity of 1000KN. The testing machine bearing surfaces were wiped clean. Also, the surfaces of the concrete cubes were wiped clean to remove any loose grit or other extraneous material from surface of concrete cube. The cube was centrally placed on the lower platen, this ensured load to be applied at the two opposite faces of the cube.

Without shock the load was applied perpendicular to the direction of casting. Each specimen were crushed under 10 minutes and the compressive load was recorded. The compressive strength of each specimen was obtained by dividing the compressive load by the contact surface area.

$F_{cu} = F/A$

F_{cu} = Compressive strength of test specimen (N/mm2)

F = Failure load applied (N)

A = Contact surface area of test specimen (mm^2)

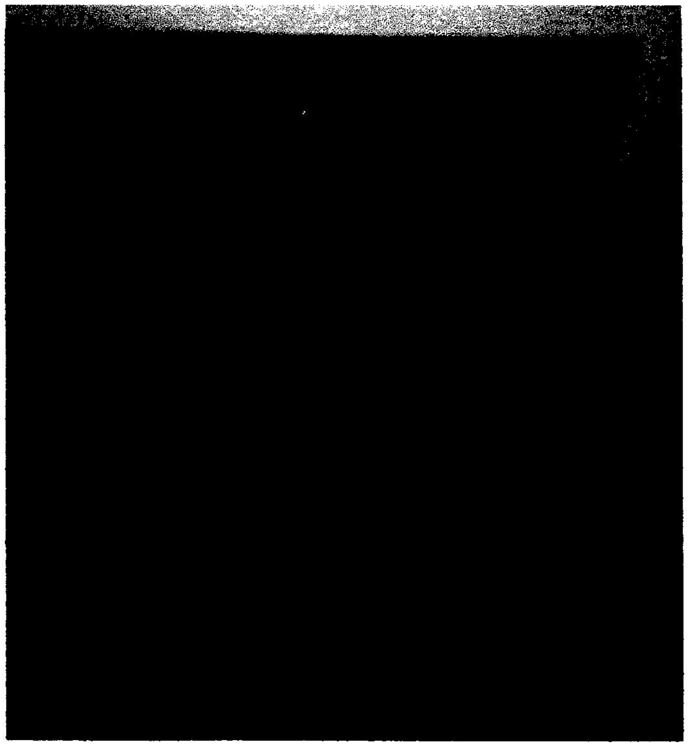

Plate 3.13: Loaded Universal Compression Testing Machine

3.2.1 Workability

Workability of concrete defined by ACI standard 116R-90 (ACI 1990b) as that property of freshly mixed concrete which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished to a homogenous condition.

The slump test was carried out in accordance with (BS 1881: Part 102 1983) using apparatus which consist of slump cone and tamping rod.

It was ensured that the internal surface of the mould was clean and damp and also free from superfluous moisture before the test was commenced. The mould was placed on a smooth, horizontal, rigid and non-absorbent surface free from vibration and shock.

The mould was held firmly against the surface, whilst it was filled in three layers, each approximately one-third of the height of the mould when tamped. Each layer was tampered with 25 strokes of the tamping rod, the strokes being distributed uniformly over the cross-section of the layer. Each layer was tampered to its full depth, ensuring that the tamping rod did not forcibly strike the surface below when the first layer was tampered and just passed through the second and top layers into the layers immediately below. The concrete was heaped above the mould before the top layer was tamped. Concrete was further added to maintain an excess, above the top of the mould throughout the tamping operation. With the mould still held down, concrete from the surface below which may have fallen onto or leaked from the lower edge of the mould was cleaned. The mould was removed from the concrete by raising it vertically, slowly and carefully, in 5 s to 10 s, in such a manner that there was minimum lateral or torsional movement to the concrete. The entire operation from the start of filling to the removal of the mould was carried out without interruption and was completed within 150 s. Immediately after the mould was removed, the slump was measured to the nearest 5 mm, using the rule to determine the difference between the height of the mould and of the highest point of the specimen being tested.

3.2.2 Sorptivity and Water Absorption

Many building materials used in the construction industry are porous. The ingress of moisture and the transport properties of these materials have become the underlying source for many engineering problems such as corrosion of reinforcing steel, and damage due to freeze-thaw cycling or wetting and drying cycles. (Patel 2009). Concrete is a porous material which interacts with the surrounding environment. The durability of mortar and concrete depends largely on the movement of water and gas enters and moves through it. The permeability is an indicator of concrete's ability to transport water more precisely with both mechanism that is controlling the uptake and transport of water and gaseous substances into cementitious material. Permeability is a measure of flow of water under pressure in a saturated porous medium while Sorptivity is materials ability to absorb and transmit water through it by capillary suction. Uptake of water by unsaturated, hardened concrete may be characterised by the sorptivity. This is a simple parameter to determine and it is increasingly being used as a measure of concrete resistance to exposure in aggressive environments. Sorptivity, or capillary suction, is the transport of liquids in porous solids due to surface tension acting in capillaries and is a function of the viscosity, density and surface tension of the liquid and also the pore structure (radius, tortuosity and continuity of capillaries) of the porous solid. (Pitroda and Umrigar 2013)

Sorptivity test was performed in accordance with (ASTM C 1585 2004). The purpose was to determine the rate of absorption of water by unsaturated concrete. Sorptivity is a function of the increased mass of a specimen resulting from absorption of water, relative to the time that one surface is exposed to water.

The concrete specimens were preconditioned by drying in an oven at 100°c until constant weight, and then allowed to cool in a sealed container for 24 hours. in order to ensure unidirectional flow through the specimen without any influence of wicking action the specimens were sealed with transparent silicon sealant on the four sides other than the exposure face to a height of 30mm. the concrete specimen were kept partially immersed in water to a depth of 10mm, at selected time (4, 8, 10, 20, 30, 60, 90, and 120) minutes the specimen was quickly removed from the water, excess water was wiped off with a damp paper towel and then the sample was weighed, the sample was then replaced in the water for the selected period.

The cumulative absorbed volume of water per unit area of inflow surface (i) was related to the square root of the elapsed time ($t^{0.5}$). The following relationship was developed.

Sorptivity (S) is a material property which characterizes the tendency of a porous material to absorb and transmit water by capillarity. The cumulative water absorption (per unit area of the inflow surface) increases as the square root of elapsed time (t)

$I=S\times t^{0.5}$ therefore $S=I/ t^{0.5}$

Where;

S= sorptivity in mm,

t= elapsed time in mint.

$I=\Delta w/Ad$

Δw= change in weight = W2-W1

W1 = Oven dry weight of concrete cube in grams

W2 = Weight of concrete after capillary

suction of water in grams.

A= surface area of the specimen through which water penetrated.

d= density of water

The slope of the line of best fit of these points was taken as the sorptivity value.

Figure 3.1 shows the sorptivity test setup, Plate (3.14, 3.15, and 3.16) shows the drying of specimen, application of sealant to concrete cubes and sorptivity specimen during the test.

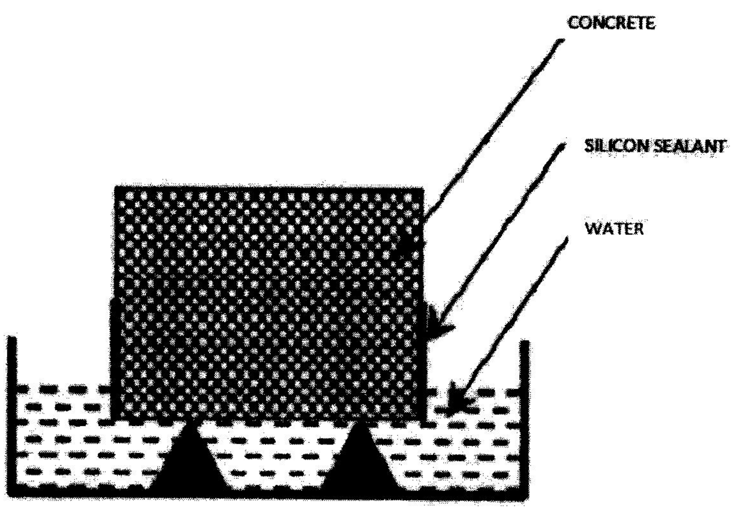

Figure 3.1: Schematic diagram of typical sorptivity test setup

Plate 3.14: Pre-Conditioning of Sorptivity Specimens inside the drying oven

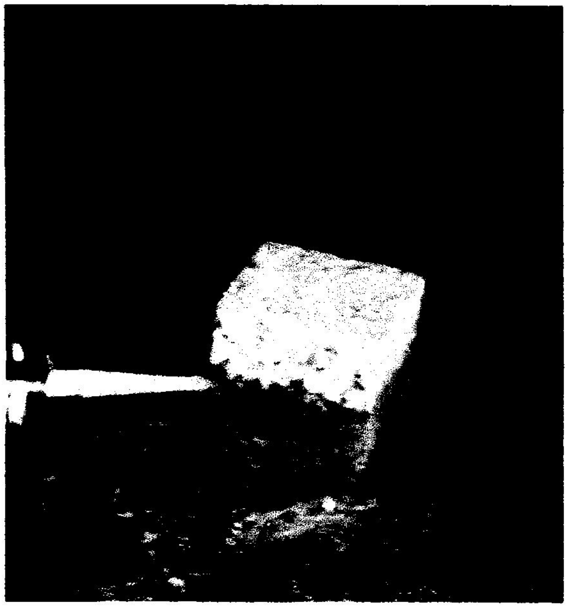

Plate 3.15: Applying silicon sealant to the sides of the concrete specimen

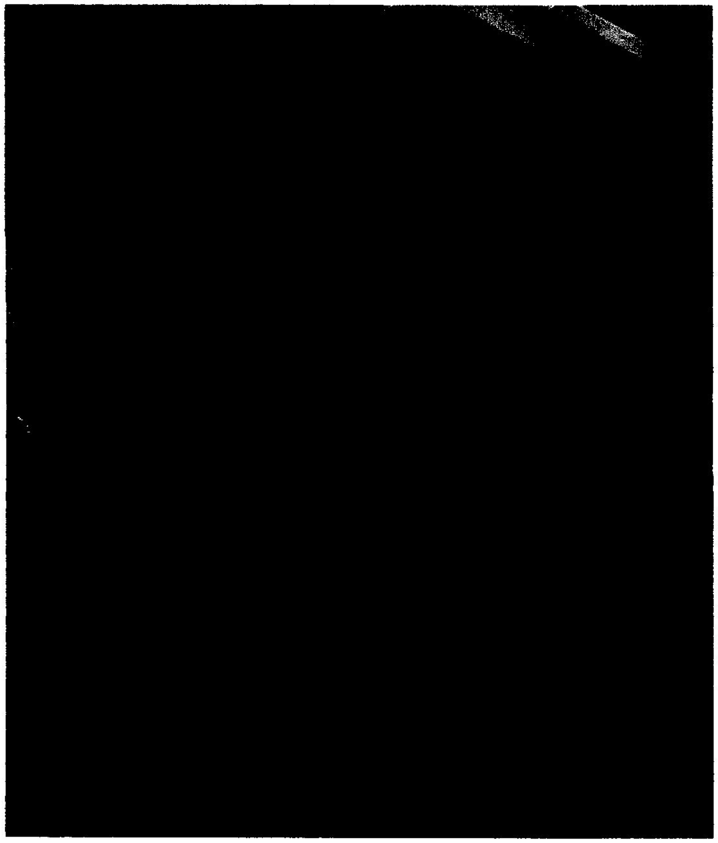

Plate 3.16: Concrete specimens during Sorptivity Test

3.2.2.0 Water Absorption

Percentage of water absorption is a measure of the pore volume or porosity in hardened concrete, which is occupied by water in saturated condition.

This test is carried out to determine the coefficient of water absorption. Coefficient of water absorption is suggested as a measure of permeability of water. This is measured by the rate of uptake of water by dry concrete in a period of 1hr. The 100mm × 100mm × 100mm concrete cubes after casting were immersed in water for 28days for curing. The concrete specimens were precondition by drying in an oven at 98 - 100°c until constant weight was reached and then allowed to cool at room temperature for 24hrs. The sides of the concrete specimen were coated with transparent silicon sealant to a height of 30mm in order to limit flow in one direction. The mass of the specimen was taken. Then the concrete specimen in a vertical position were kept partially immersed to a depth of 10mm. The concrete specimen were taken out at 1hr immersion in water. Excess water on the surface of the concrete specimen was wiped with a damp paper towel. The concrete specimen was weighed.

The coefficient of water absorption (Ka) was obtained by using the following expression:

$$\left(\frac{Q}{A}\right)^2 \times \frac{1}{t} = Ka$$

Where Q = the amount of water absorbed in (m^3)

A = the cross-sectional area of concrete specimen in contact with water (m^2)

t = Time (sec)

Ka = Coefficient of water absorption (m^2/s)

3.2.3 Microstructure

The microstructure of a concrete is of a composite material, composed of aggregate, cement paste and the interface between them. The characterization of concrete microstructure entails the characterization of the cement paste and the paste/aggregate interface. Characterizing the mineralogy of the concrete samples can be done in several ways. The SEM identifies the morphology of the structure. Energy Dispersive Spectroscopy (EDS) allows high resolution identification of elements and compounds present in prepared 2-D cross-sections of aggregate samples.

SEM is an effective tool for visually examining the particles that are too small to be seen under an optical microscope. The SEM works by aiming an electron beam at the surface of the specimen. When the electron beam strikes a solid object, the electrons are either scattered or absorbed. The collection of these responses is what forms the SEM image. (Shodhganga 2017)

Energy dispersive spectroscopy is performed to determine the composition of elements present in the sample. Any smaller size particles can be analyzed at large magnification using EDS. Depending upon the samples, several points are selected on the SEM image and analyzed through EDS. EDS detects the elements present in a specimen based on the detection of X-Rays emitted by that specimen. The X-Ray photons emitted by the specimen are collected by EDS and converted into a number of "counts" at each emission voltage. (Shodhganga 2017)

A portion of each crushed sample was prepared by crushing or cutting to smaller bits and then subjected to Scanning Electron Microscopy. The EDX data were obtained using a micro-analytical unit that featured the ability to detect the small variations in trace element content. Areas used for EDX analysis corresponded directly to the SEM morphological examination.

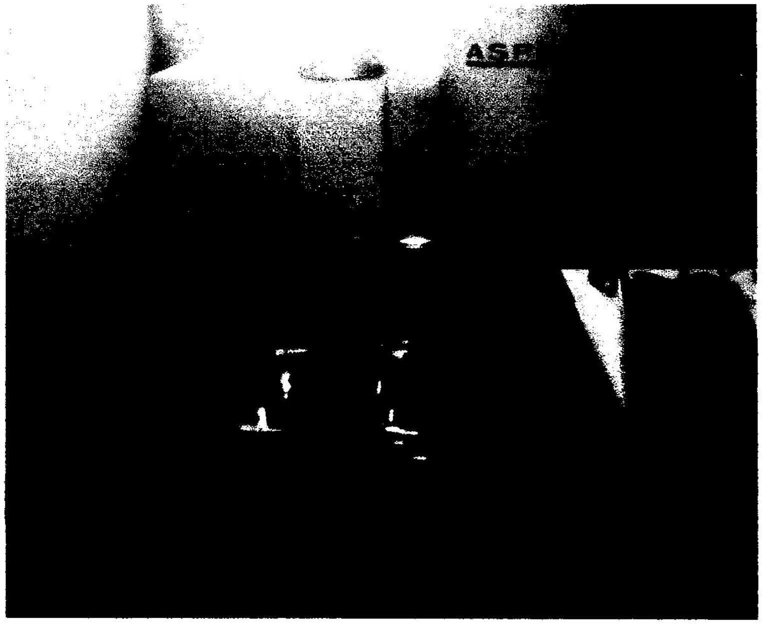

Plate 3.17: Loaded SEM/EDX analysing machine

Plate 3.18: Concrete samples on the sample holder

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Sieve Analysis (Particle Size Distribution)

Particle size distribution was carried out to ensure that the resulting concrete is workable, since good grading of aggregate is one of the factors in producing good concrete. The sieve analysis result is shown in Appendix B1.

The maximum size was 10mm for PKS aggregate and 20mm for granite aggregate. The particle size distribution graph (Figure 4.1) indicated that the aggregates were uniformly graded. The coarse aggregate particle size distribution is of great importance in achieving good concrete workability and compactibility (Afolayan 2015). In general, studies have shown that uniformly graded aggregate contributes positively to the overall quality of concrete than gap graded aggregates (Chandra and Berntsson 2002). According to (Mehta and Monteiro 1993) uniformly distributed aggregates lead to higher packing resulting in concrete with higher density, less permeability, decreased cost of production, easy placement and enhanced overall quality of the concrete, and improved abrasion resistance.

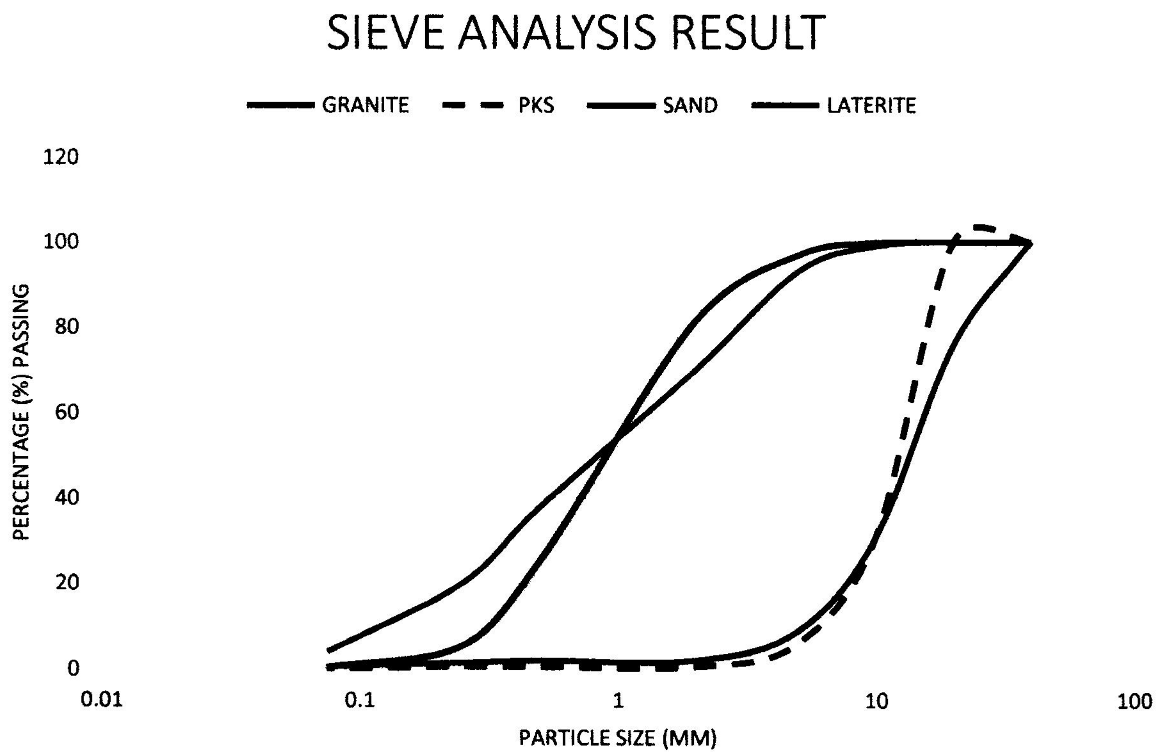

Figure 4.1: Particle size distribution of fine and coarse aggregate

4.1 Specific Gravity

The specific gravity obtained for the granite, sand, laterite, and PKS aggregates were 2.75, 2.77, 2.18 and 1.33 respectively; (Table 4.1). According to British Standard BS 812: Part 2: 1995, the majority of natural aggregate have specific gravity between 2.60 and 2.70. Aggregates with specific gravity less than about 2.4 are classified as lightweight while normal weight concrete aggregates have specific gravity around 2.6 (Popovics 1992) It can be noticed that specific gravity of the PKS aggregate is greatly low compared to that of granite, the high porosity of PKS is likely the reason for this. The specific gravity of PKS aggregate is about 50% lower than the specific gravity of naturally occurring aggregate, this implies that the more PKS aggregate would be required for the concrete mix.

4.2 Porosity

The porosity obtained for the granite, sand, laterite and PKS aggregate are 1.52%, 25%, 11.39%, 5.88% respectively. The presence of internal pores in the aggregate particle and the characteristics of these pores are of paramount importance in the study of its properties (Afolayan 2015). The porosity of aggregate influences such properties of aggregate as the bond between it, the hydrated cement paste, the resistance of concrete to freezing and thawing as well as its chemical stability and resistance to abrasion. Since aggregate represents three-quarters of the volume of concrete, it is clear that the porosity of aggregate materially contributes to the overall porosity of concrete. The result of the porosity test is shown in Table 4.1.

4.3 Moisture Content

The moisture content obtained for the sand, laterite, PKS and granite aggregate are 0.6%, 1.14 %, 3.15%, 0.009% respectively. Table 4.1 shows the moisture content result of the aggregate samples. It is observed that laterite aggregate had the highest moisture content, while granite aggregate had the lowest moisture content. The rate at which aggregate absorb certain quantity of water depends on the porosity of the aggregate sample. Moisture content is important in the control of the nature of cement especially in terms of workability and quality. Abrams law stated that, all other things been equal, compressive strength of concrete is dependent on the ratio of mass of water to cement.

It should be noted that if the aggregates are dry they absorb water from the mixing water and thereby affect the concrete's workability and, on the other hand, if the aggregate contains moisture they contribute extra water to the mix and thereby increase the water/cement ratio. Both conditions are harmful to the quality of concrete, in making quality concrete it's necessary that measures should be taken for free moisture (Moisture content) so that the water/cement ratio is kept exactly as per the design.

4.4 Loose Bulk Density

The value of bulk density of granite, laterite, sand and PKS aggregate were 1660 kg/m^3, 1220 kg/m^3, 1786 kg/m^3 and 661 kg/m^3 respectively. Bulk density shows how densely the aggregate is packed when filled in a standard manner. The bulk density depends on the particle size distribution and shape of the particles. Table 4.1 shows the bulk density of the aggregate samples.

It should be noted that the higher the bulk density the lower the void content to be filled by sand and cement. Since sand aggregate had maximum bulk it alludes that it has minimum voids and it's the right aggregate sample for making economical mix. PKS had the lowest bulk density and the result shows that it had about 60% less weight compared to both the fine and coarse aggregate making it a light weight aggregate.

4.5 Water Absorption

The water absorption result of the PKS aggregate obtained after 24 hours was 5% while that of granite aggregate was 2.04%. This indicates that the PKS aggregate is more porous than the granite aggregate. The high water absorption properties of the PKS can be attributed to the high porosity and large interconnecting pore structure of the aggregate (Concrete Technology 2015). Since the water absorption of the granite is low it is reasonable to conclude that the granite absorbs lesser amount of mixing water during concrete production and PKS absorbs higher amount of mixing water during concrete production.

Generally, the 24 hours water absorption values of PKS have been reported to be high ranging from 14% to 33% (Ndoke 2006). The average 24 hours water absorption for PKS aggregate obtained in their study was about 23.4%, also the water absorption for PKS aggregate obtained from the study carried out by (Alex 2015) was 18%, while for granite it was 0.68%. The table below shows the water absorption of the PKS and Granite aggregate.

4.6 Aggregate Crushing Value (ACV)

The aggregate crushing value (ACV) obtained from the study for PKS and granite aggregate were 3.122% and 14.65%. Table 4.1 shows the aggregate crushing value (ACV) of the PKS and granite aggregate. The ACV provides a relative measure of resistance to crushing under a gradually applied compressive load. Aggregate with lower ACV are preferred for better resistance to compressive load and surface abrasion (Alex 2015). The recommended maximum ACV stipulated in BS 812: Part 110: 1990 for aggregate for concrete production is 30% and the aggregate crushing value should not be more than 45% for wearing surfaces. Hence, the aggregate are suitable for concrete production since they are within the recommended limits. (Okpala 1990) In his study of Palm kernel shell as a lightweight aggregate in concrete obtained a crushing strength of PKS as 12.06 N/mm2 compared to about 181 N/mm2 for granite aggregate. This indicates that the aggregate crushing value test may not be appropriate for PKS aggregates as observed for other weak aggregates by (Neville 1981). It is likely that after crushing at the initial stage, the aggregates become compact with little or no crushing at later stages of loading, and thus the better ACV property than normal weight aggregates (Alex 2015).

4.7 Aggregate Abrasion Value (AAV)

The result obtained for the AAV in the study were 0.85% and 1.97% for PKS and granite aggregate respectively as shown in Table 4.1. The higher the AAV, the lower the resistance to abrasion. The level of wear in the abrasion test indicates the potential increase in the amount of fines in the concrete when the fresh concrete is subjected to prolong mixing (Popovics 1992).

Aggregate abrasion test is of great importance if the aggregate is to be used for road construction, warehouse floors and pavement construction (Afolayan 2015). The code specified that for aggregate to be used for any of the above type of construction it should have max abrasion value between 30% - 50%. Since the aggregate abrasion value obtained in the study is far less than 30%. Hence, both PKS and granite aggregate are suitable for construction as it satisfied the abrasion provision in the code. This means that both aggregate have high resistance to wear.

4.8 Aggregate Impact Value (AIV)

The aggregate impact value (AIV) obtained for PKS and granite aggregate are 0.61% and 0.98% respectively, Table 4.1 presents the AIV result of the aggregates. The aggregate impact value gives a relative measure of the toughness of aggregate or resistance of aggregate to sudden shock or when impact loads are applied on them. The British standard (BS 812: Part112: 1990 and BS 882:1992) specified maximum value of 25% when the aggregate is to be used in heavy duty floors, 30% when the aggregate is to be used in concrete for wearing surfaces and 45% when it is to be used in other concretes. This implies that aggregate of higher AIV are weaker than aggregate of lower AIV. Since both aggregates used in this study are within the recommended limit, they are therefore adequate for production of concrete of good impact resistance.

Table 4.1: Physical Properties of aggregate

Properties	Coarse aggregate		Fine aggregate	
	PKS	Granite	Sand	Laterite
Maximum aggregate size	10	20	—	—
Specific gravity	1.33	2.74	2.76	2.18
Aggregate impact value	0.6	0.98	—	—
Aggregate crushing value	14.65	3.12	—	—
Aggregate abrasion value	0.85	1.97	—	—
Moisture content	0.60	0.01	1.14	3.15
Porosity	5.88	1.52	25	11.39
Bulk density	661	1660	1786	1220
Water absorption	5	2.04	—	—

4.9 Workability

The workability of the fresh concrete mixes experience reduction with the partial replacement of the granite aggregate and sand aggregate with PKS aggregate and laterite aggregate.

The control mix had a slump of 10mm as shown in Table 4.2, while mix containing 0% PKS had slump of 6mm.

The mix containing 10% PKS had slump of 0mm (zero slump). This is as a result of the replacement of granite aggregate with PKS aggregate, which have a higher water absorption rate than granite aggregate. At 50% PKS content shear slump took place and the test was repeated, again, shear slump occurred. (Neville and Brooks 2008) Stated that the reoccurrence of shear slump indicates lack of cohesion in the mix.

It was observed that the further increase in the PKS content in the concrete mix reduced the workability of the concrete.

Plate 4.1: Slump test of freshly mixed concrete

Table 4.2: Slump Test Results of Fresh Concrete Mix

CONCRETE SAMPLE	SLUMP (mm)	Degree of Workability
Control	10	Very low
0% PKS	6	Very low
10% PKS	0	Very low
20% PKS	0	Very low
30% PKS	0	Very low
40% PKS	0	Very low
50% PKS	0	Very low

4.10 Density of Concrete

The average densities of the concrete specimen are presented in the Table 4.3 below. The densities of the concrete cubes were between 1767.90kg/m^3 and 2518.31 kg/m^3 between 7 and 90 days.

Table 4.3: Density of Concrete

S/N	AVERAGE DENSITY OF CONCRETE (Kg/m^3)					
	7 DAYS	14 DAYS	21 DAYS	28 DAYS	60 DAYS	90 DAYS
CONTROL	2395.14	2419.75	2424.69	2518.31	2469.18	2488.18
0 PKS	2204.94	2479.21	2449.38	2489.29	2399.39	2395.41
10 PKS	2219.26	2351.28	2360.49	2418.75	2340.61	2330.69
20 PKS	1896.30	1975.31	2216.67	2227.26	2200.74	2192.09
30 PKS	1792.59	2025.85	1990.12	2021.67	1976.41	1950.61
40 PKS	1841.98	1924.92	1965.43	2025.70	1996.14	1932.47
50 PKS	1767.90	1819.10	1916.05	2055.93	2001.18	1900.47

The air-dry density of concrete is important for the weight of the structure and it defines the compactness, the amount of reinforcement and sizes of structural members in a particular structure. (Lydon 1982) Pointed out that for some lightweight aggregates, the compressive strength depends on the type of aggregates and increases with increase in density. The density of concrete depends on the specific gravity of the aggregates, sand content and the type of sand (Alengaram *et al.,* 2010). Given the low specific gravity of the PKS, the resultant density values around limit of 2000 Kg/m^3 could be attributed to the use of river sand and laterite as fine aggregates which have a comparatively higher specific gravity.

The relatively low weight of the PKS concrete is brought about by the lightweight of PKS and low compactness of PKS concrete due to the highly irregular shapes of the shells (Teo D *et al.,* 2007). Thus, the irregular aggregates are most likely to result in increased void content of the PKS concrete.

(Rossignolo *et al.,* 2003) Concluded that the density of LWC is often more important than the strength since LWC with the same compressive strength level may reduce the self-weight of resulting concrete as a result of a decreased density.

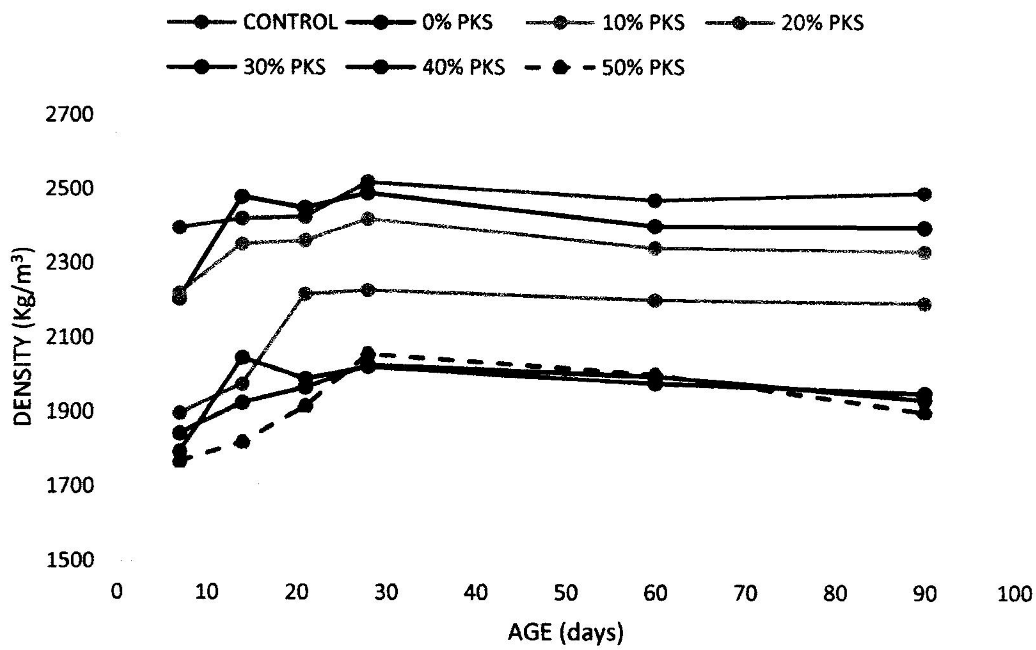

Figure 4.2: Density of concrete at different curing ages and PKS content

4.11 Compressive Strength of Concrete

The relationship between the compressive strength with age is shown in the Figure 4.3 It was observed that the compressive strength of concrete increased rapidly with age until the 28th day after which strength developed or reduced gradually until the 90th day. Generally, the control concrete had the greatest compressive strength at all the curing ages, as shown in Figure 4.3 the compressive strength of concrete at 28 days were in range of 7.12 N/mm2 to 24 N/mm2 and those of 7 days varied from 4.65 N/mm2 to 15.99 N/mm2.

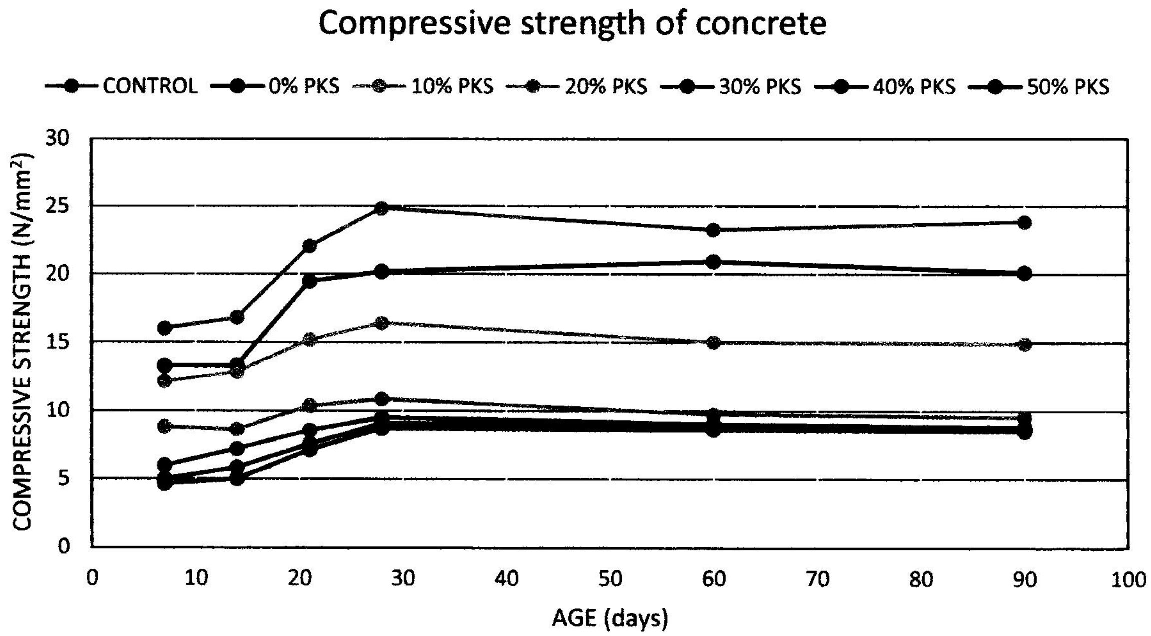

Figure 4.3: Compressive strength of concrete at different curing ages and PKS content

Table 4.4: Compressive strength of concrete

S/N	AVERAGE COMPRESSIVE STRENGTH OF CONCRETE (N/mm2)					
	7 DAYS	14 DAYS	21 DAYS	28 DAYS	60 DAYS	90 DAYS
CONTROL	15.99	16.77	22.03	24.82	23.22	23.81
0 PKS	13.25	13.29	19.45	20.16	20.89	20.10
10 PKS	12.11	12.81	15.17	16.39	15.01	14.89
20 PKS	8.28	8.60	10.34	10.84	9.72	9.52
30 PKS	5.96	7.18	8.54	9.49	9.01	8.79
40 PKS	4.97	5.82	7.53	9.06	8.85	8.62
50 PKS	4.65	5.00	7.12	8.71	8.63	8.53

From the Figure 4.4, it was observed that the compressive strength of concrete reduced gradually as the percentage of PKS in concrete increased, this decrease in compressive strength may be due to several reasons not limited to; decrease in content of natural coarse aggregate, increase in laterite content in the concrete, reduction in bond strength between the aggregates with the introduction of PKS aggregate and particle size of the PKS aggregate.

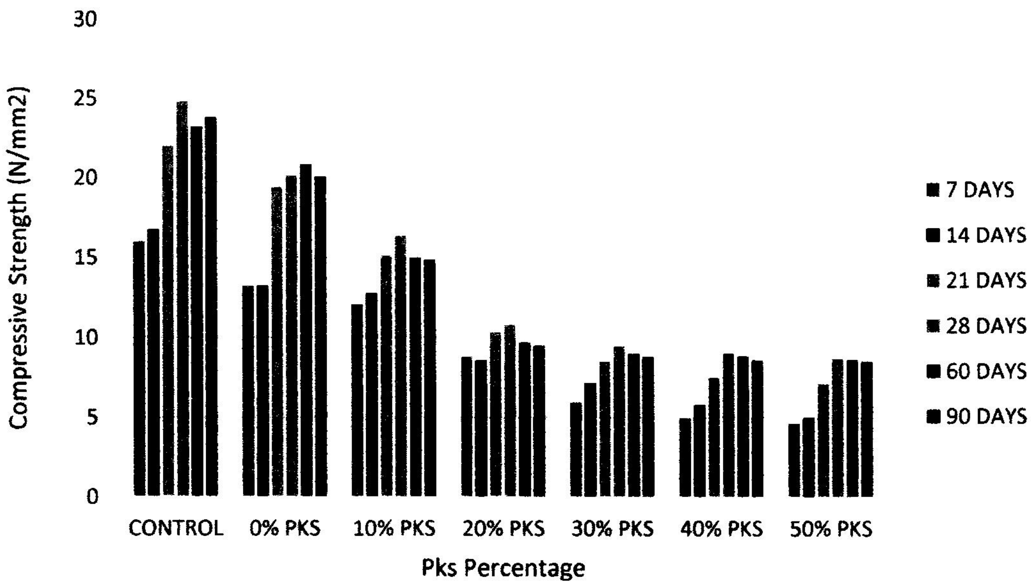

Figure 4.4: Comparison of concrete compressive strength at different PKS content and curing ages

As a result of the low water - cement ratio of concrete mix, the strength development during the first 7 days could be attributed to the higher hydration rate and thus strength of the cement paste. Beyond 7 days, the strength of the cement paste in the PKS concrete begins to approach the strength of the aggregates which limits further increase in compressive strength (Okpala 1990). (Alex 2015) Stated that it was more likely that rather than strength of PKS aggregates, strength at higher curing periods will depend on the PKS-cement paste bond, as the hydration of cement paste will have run its course.

(ASTM C330 1999) Recommends a minimum compressive strength of 17 N/mm2 for structural LWC at 28-days. While (BS 8110 1997), recommends a minimum compressive strength of 15 N/mm2. The 28th day compressive strength of concrete produced, had higher than the minimum required strength recommended by BS 8110 at 10% PKS content and 0% PKS content for ASTM C330. This shows that PKS cannot be used to replace granite in producing LWC for structural applications. This contradicted the findings of (Alex 2015) who reported a higher than minimum required compressive strength for both ASTM C330 and BS 8110, which was suitable for producing LWC for structural applications.

The PKS aggregates were parabolic, circular or semicircular, flaky and elongated and these are controlling factors for compressive strength (Chen *et al.,* 1999). The flaky and elongated shape of the PKS resulted in greater demand for cement-sand paste for a given mix as the total surface area of aggregate to be coated with the paste increased (Gupta and Gupta 2004). The result is that corresponding concretes will have lower workability, be harsh, and be of lower strength where the cement paste is not sufficient to lubricate the aggregates for the necessary bonding (Alex 2015).

Alex in his research shear strength properties of structural lightweight reinforced concrete beams and two-way slabs using palm kernel shell coarse aggregates, studied the failure of PKS concrete cubes and he observed that failure is been caused by a weak bond between the PKS and the cement matrix. Failure was observed to be along the smooth convex surface of the PKS aggregates.

(Mahmud *et al.,* 2009) reported that failure of PKS concrete in compression was as a result of the failure of the PKS aggregates. (Mannan and Ganapathy 2002) Indicated that failure of PKS concrete at 90 days is controlled more by the strength of PKS-cement paste bond than by the strength of PKS aggregate itself.

(Alex 2015) Suggested that the strength of PKS concrete depends on the strength of the mortar, and the interfacial bond between the PKS and the cement matrix at least at early stages of hydration.

4.12 Sorptivity and Water Absorption of Concrete

The sorptivity obtained for the 28 days and 90 days concrete cubes with 0% PKS, 10% PKS, 20% PKS, 30% PKS, 40% PKS and 50% PKS are shown in Table 4.5.

It is observed that concrete containing 0% PKS had the lowest sorptivity while concrete containing 50% PKS had the highest sorptivity.

The result obtained showed that the sorptivity of concrete increased proportionally with increase in PKS content of concrete, this can be related to the fact that increase in PKS reduced the bulk density of concrete and in the study of sorptivity in concrete by (Hall and Yau 1987), it was reported that sorptivity of concrete varied with the mix, water-cement ratio, density of concrete, porosity and the compaction of concrete, they observed that sorptivity increased with increase in porosity, water-cement ratio, it also increased with decrease in bulk density of concrete.

(Cannan 2003) In his research, Combined effects of mineral admixtures and curing conditions on the sorptivity coefficient of concrete, it was observed that as the compressive strength of concrete increased, the sorptivity reduced under different curing condition.

(Esam Elawady *et al.,* 2014) investigated Strength, permeability and sorptivity of concrete and their relation with concrete durability. They concluded that curing by water, air or moisture is critical to sorptivity than strength, that is, the concrete sorptivity is highly sensitive to curing rather than its compressive strength.

Table 4.5: Sorptivity test result for concrete specimens

PKS % IN CONCRETE	SORPTIVITY (mm/min$^{0.5}$)	
	28 DAYS	90 DAYS
0	0.222	0.222
10	0.267	0.312
20	0.367	0.319
30	0.370	0.325
40	0.388	0.367
50	0.412	0.415

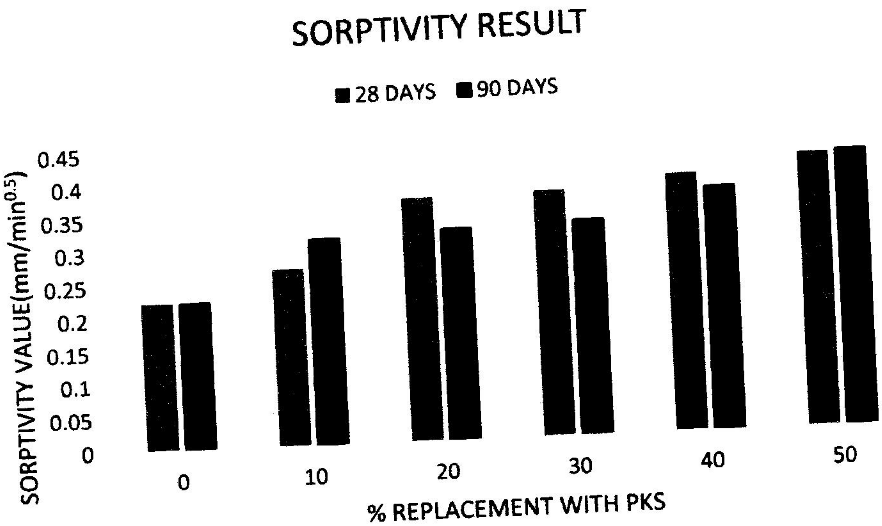

Figure 4.5: Sorptivity test result

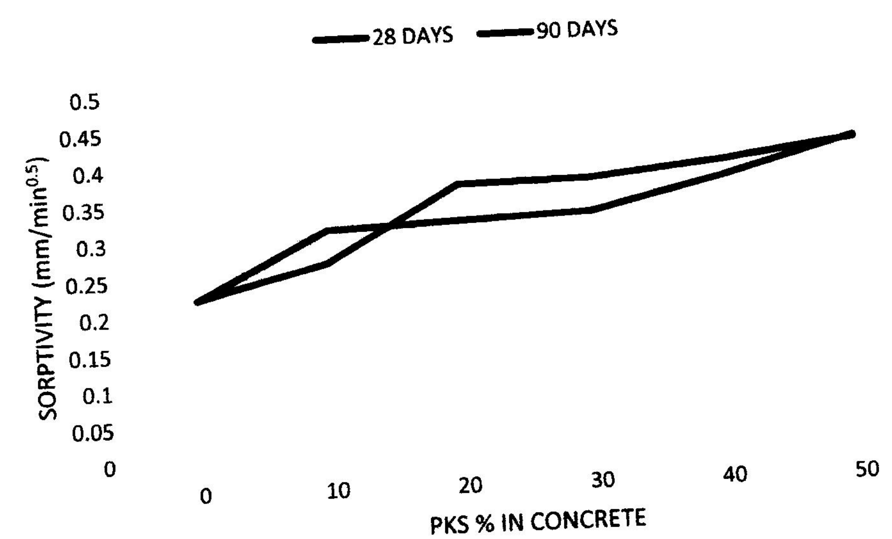

Figure 4.6: Sorptivity plot for 28 days and 90 days concrete sample

4.12.0 Water Absorption

The result of the water absorption test is shown in Table 4.6. From the result it's evident that the water absorption of both 28 days and 90 days lateritic concrete was lowest at 0% PKS content and as the PKS content increased the water absorption showed an increasing trend. Figure 4.7 shows water absorption plot for 28 and 90 days lateritic concrete cubes.

Table 4.6: Water Absorption for the concrete samples

PKS % IN CONCRETE	t (sec)	28 DAYS		90 DAYS	
		(Q/A) m $\times 10^{-3}$	Ka (m^2/s) $\times 10^{-9}$	(Q/A) m $\times 10^{-3}$	Ka (m^2/s) $\times 10^{-9}$
0	3600	3	2.50	3	2.50
10	3600	4	4.44	3	2.50
20	3600	4	4.44	4	4.44
30	3600	3	2.50	4	4.44
40	3600	5	6.90	5	6.90
50	3600	5	6.90	5	6.90

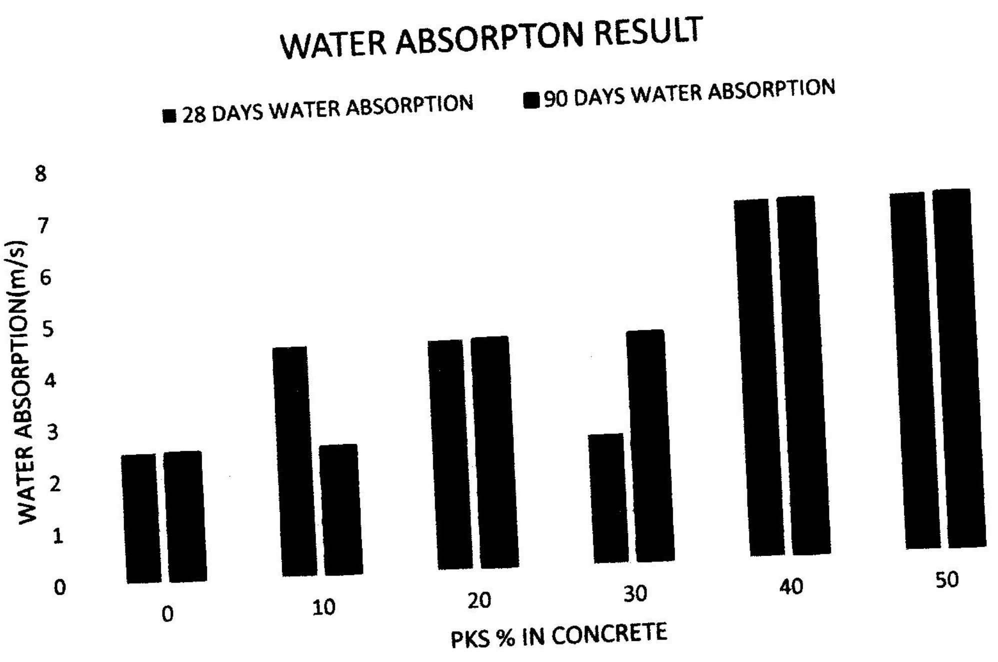

Figure 4.7: Water absorption plot for 28 and 90 days lateritic concrete cubes.

4.13 Microscopy

The figures below show the microscopic image of the concrete samples analysed using scanning electron microscope (SEM) in the back scattered electron mode with an accelerating voltage of 16.0 Kev. The back scattered Intensity was set to the same parameter for each sample, at display magnification of 25. Table 4.7 shows the elemental composition of each of the concrete samples.

The SEM analysis of 0% PKS concrete is shown in the figure below;

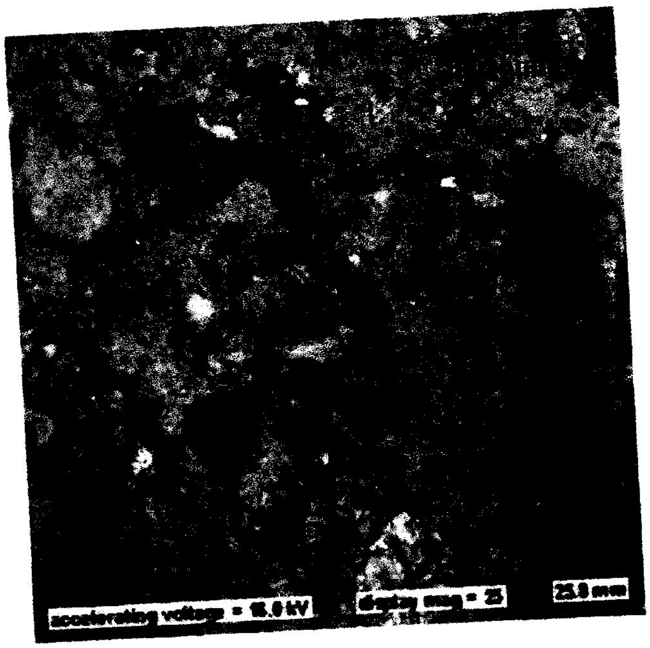

Figure 4.8: SEM image of concrete sample with 0% PKS

From Figure 4.8, at display magnification of 25, the distribution of both coarse and fine aggregate can be seen in a matrix of the cement paste.

The Figure below shows the EDX result of the concrete sample.

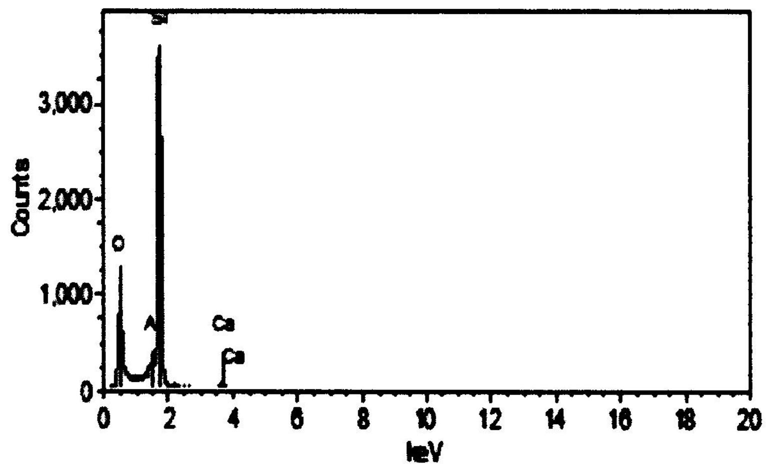

Figure 4.9: EDX analysis of concrete sample with 0% PKS

From Figure 4.9, it is found that the elements present in the concrete sample are calcium, alumina, silica, oxides e.t.c. The calcium reacts with alumina and oxides and produces tri calcium aluminate, which is the reason for early setting.

The SEM analysis of 10% PKS lateritic concrete is shown in the figure below;

Figure 4.10: SEM image of lateritic concrete sample with 10% PKS

From Figure 4.10, voids/pores can be seen in the hydrated cement paste, also pore bonding between the granite aggregate and the cement paste is noticed, this can be related to the high adhesive properties of both the cement and laterite, their adhesion affects the bonding between the granite aggregate and the cement paste.

Figure 4.11 showed that the concrete contained calcium, alumina, silica and oxides.

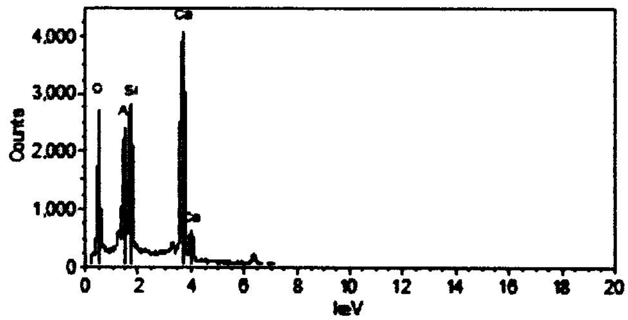

Figure 4.11: EDX analysis of lateritic concrete sample with 10% PKS

The SEM analysis of 20% PKS concrete is shown in the figure below;

Figure 4.12: SEM image of concrete sample with 20% PKS

PKS fibres and sand particles can be seen in the hydrated cement paste, cracks can also be seen around it. From the figure it becomes evident that PKS affect the bonding between the cement paste and the aggregates by creating a bridge in between them. This affects the concrete because when the concrete is loaded, a differential movement between the aggregate and cement paste occurs which promotes the formation of cracking in the concrete sample. Cracks result in poor strength performance of the concrete.

The Figure below shows the result of the EDX analysis of the concrete sample.

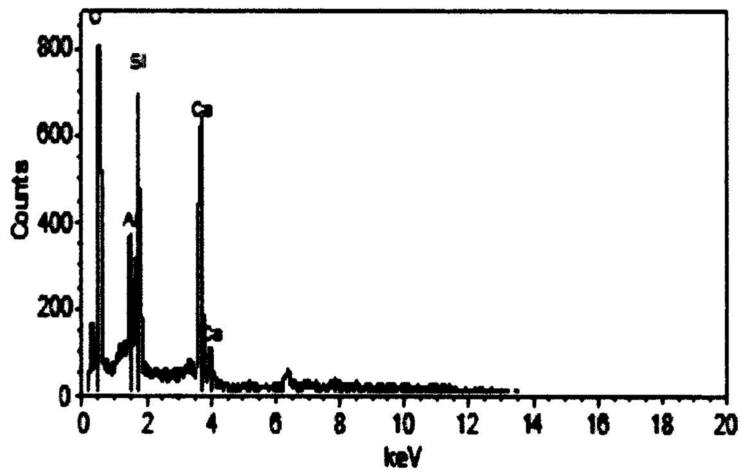

Figure 4.13: EDX analysis of concrete sample with 20% PKS

From Figure 4.13 and Table 4.7, it is evident that the concrete sample contains calcium, alumina, silica, oxides e.t.c. The calcium reacts with alumina and oxides and produces tri calcium aluminate, which is the reason for early setting.

The SEM analysis of 40% PKS concrete is shown in the figure below;

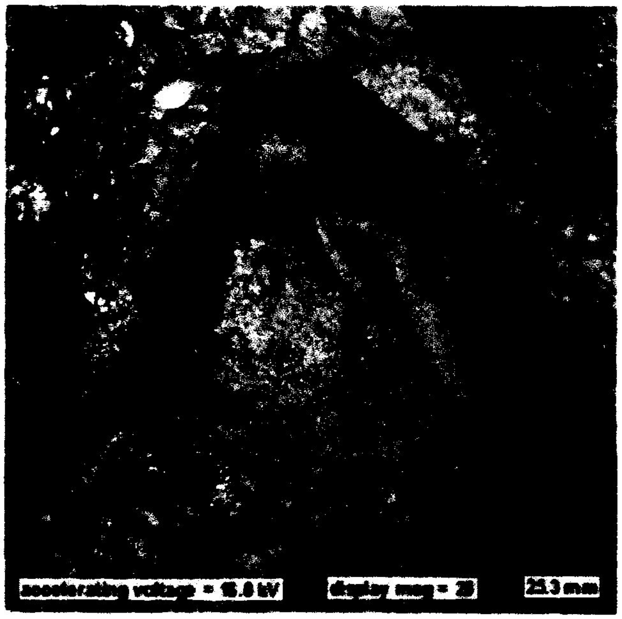

Figure 4.14: SEM image of concrete sample with 40% PKS

From Figure 4.14, Cracks are observed around the PKS aggregate, cracks in concrete depend on several factors some of them which are; Aggregate size and grading, cement content, water cement ratio e.t.c. due to the high water absorption property of PKS aggregate, during mixing the PKS tend to absorb most of the mixing water around it, this affects the chemical reaction between the cement paste constituents and aggregates, and also the formation of calcium silicate hydrates which is responsible for the adhesion or bonding in concrete.

Figure 4.15 shows the laterite concrete's elemental composition.

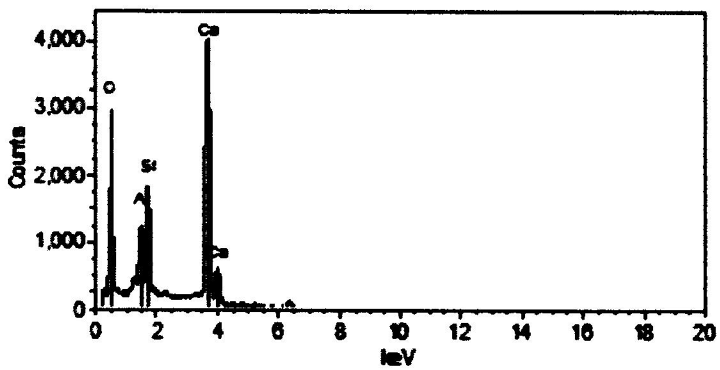

Figure 4.15: EDX analysis of concrete sample with 40% PKS

The SEM analysis of 50% PKS concrete is shown in the figure below;

Figure 4.16: SEM image of concrete sample with 50% PKS

From Figure 4.16, cracks and voids can be seen in the concrete. This cracks and voids in the concrete can be the reason why laterite concrete with 50% PKS tend to fail at a lower stress, because it wont take much stress to extend the cracks that already exist. The volume of voids and the cracks present also affect the stiffness or the elastic modulus of the concrete. Each component (hydrated cement paste and aggregates) may have great stiffness but the stiffness of the concrete as a whole is reduced due to the voids and cracks. (Nicolas *et al.,* 2001) in their research, "Experimental analysis of compaction of concrete and mortar" reported that when concrete is subjected to high confinement compressive stresses, the non-linear response of concrete is not only the result of microcracking and microcrack sliding but also the consequence of material crushing.

The Figure below shows the EDX result of the concrete sample.

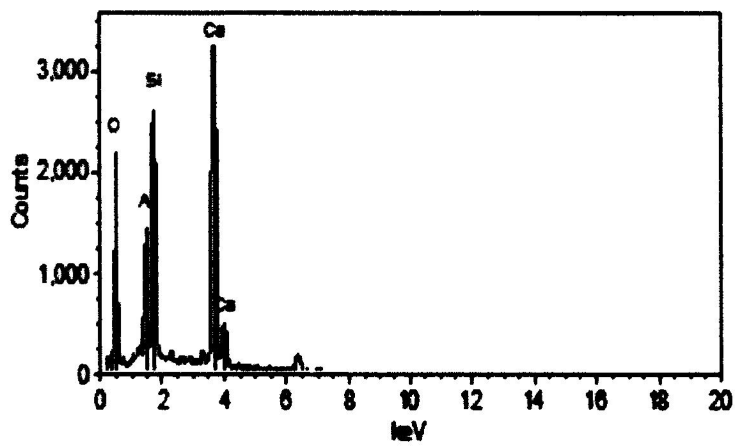

Figure 4.17: EDX analysis of concrete sample with 50% PKS

From Figure 4.17 and the Table 4.7, it is evident that the concrete sample contains calcium, alumina, silica, oxides e.t.c. The calcium reacts with alumina and oxides and produces tri calcium aluminate, which is the reason for early setting.

Table 4.7: Elemental composition of the concrete samples

	0% PKS CONCRETE	10% PKS CONCRETE	20% PKS CONCRETE	30% PKS CONCRETE	40% PKS CONCRETE	50% PKS CONCRETE
ELEMENTS	Normalized K-Ratio rounded to first decimal	Normalized K-Ratio rounded to first decimal	Normalized K-Ratio rounded to first decimal	Normalized K-Ratio rounded to first decimal	Normalized K-Ratio rounded to first decimal	Normalized K-Ratio rounded to first decimal
Na	0.0	0.0	0.0	0.0	0.0	0.0
Al	0.0	3.6	3.1	1.2	1.2	7.7
Si	51.7	8.8	13.0	4.1	6.2	18.9
S	0.7	0.3	0.2	0.0	0.2	0.5
Cl	0.3	0.1	0.0	0.0	0.1	0.0
K	0.0	2.3	1.8	2.2	2.0	1.3
Ca	2.7	30.9	27.7	37.9	36.1	17.5
Ti	0.3	0.4	0.3	0.3	0.3	0.5
Cr	0.3	0.1	0.0	0.0	0.0	0.3
Mn	0.0	0.1	0.3	0.0	0.0	0.0
Fe	0.1	3.8	5.2	0.5	2.0	5.8
Ni	0.4	0.0	1.5	0.0	0.0	0.1

Cu	0.6	0.0	0.0	0.1	0.2	0.0
Zn	0.0	0.5	0.0	0.0	0.0	0.4
Br	10.5	7.0	5.7	2.8	5.9	19.6
Sr	0.0	0.7	0.0	0.0	0.0	0.4
Zr	7.2	0.3	0.4	0.1	0.0	0.9
Ag	1.1	0.3	0.7	0.6	0.5	0.4
Sn	1.0	12.9	10.7	16.8	14.8	7.2
Sb	2.0	23.7	21.8	30.0	27.0	14.2
Ba	0.0	1.6	3.1	2.2	2.2	1.7
La	0.2	0.2	1.5	0.3	0.3	0.2
Ce	0.2	0.0	0.0	0.0	0.0	0.0
W	0.0	0.0	0.0	0.0	0.8	0.0
Au	7.7	0.0	0.0	0.0	0.0	0.5
Hg	10.0	1.6	2.2	0.2	0.3	1.7
Pb	2.9	0.7	0.6	0.4	0.0	0.2
Bi	0.0	0.0	0.0	0.0	0.0	0.0

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.0 Conclusion

Lightweight concrete can be used for lots of structures ranging from complex structures to simple low-cost housing and rapidly erected temporal structures.

The partial replacement of granite with agricultural waste (PKS) and replacement of sand with laterite in concrete production has gained cconsiderable importance because of the requirements of environmental safety and more durable construction in the future.

This study looked at the physical and mechanical properties of PKS, laterite, sand, and granite aggregates, the physical and mechanical properties of fresh and hardened concrete containing PKS and laterite aggregate. Aggregate properties such as aggregate impact value (AIV), aggregate crushing value (ACV), Los Angeles abrasion value (AAV), water absorption and bulk density were estimated.

Based on investigation the following conclusion can be drawn:

i. The physical and mechanical properties of the PKS aggregate are satisfactory, based on BS 882 (1992). Mechanical properties such as aggregate impact and Los Angeles abrasion values are found to be lower than corresponding values for the granite aggregates. PKS aggregates possess high abrasion resistance which suggests that PKS aggregates can be used as a floor finish. PKS aggregates have high water absorption (about 5%) compared to 2.04% for granite aggregates, thus the workability of the concrete can adversely be affected at the mixing stage with subsequent effect on the hydration of the cement and the creation of voids in finished concrete.

ii. Based on the physical properties of PKS aggregate, PKS is a potential construction material and can be used as a replacement of granite aggregates for low applied load situations. Its use in construction also solves the environmental problem of disposal of the agriculture waste material.

iii. The physical and mechanical properties of the laterite aggregate are satisfactory, based on BS 882 (1992). Mechanical properties such as specific gravity and bulk density values are found to be lower than corresponding values for the sand aggregates. Laterite aggregates possess high moisture content which is as a result of its high porosity, this property can affect the workability of the concrete at the mixing stage with subsequent effect on the hydration of the cement. Based on the physical properties of laterite aggregate, laterite aggregate is a potential replacement for sand.

iv. The compressive strength of the concrete containing PKS and laterite aggregate at 28day test, ranged from (8.71N/mm2 – 20.16N/mm2). Only concrete with 40% laterite and 0% - 10% PKS content produced concrete with compressive strength higher than the minimum required strength of 15N/mm2 for structural LWC as given by BS 8110. Thus, concrete with PKS content greater than 10% will negatively affect its compressive strength.

v. The 28 day concrete has a density ranging from 2055.93 kg/m^3 to 2518.31 kg/m^3. In all the cases, the density of the concrete produced decreased with increase in the percentage replacement of coarse aggregate with PKS aggregate.

vi. The sorptivity of the 28 day concrete ranged from 0.222 to 0.412. The sorptivity showed sensitivity to the PKS content in the concrete, as the PKS content increased the sorptivity of the concrete increased proportionally.

vii. The SEM result of the concrete samples indicated that inclusion of PKS in the concrete affected the bonding between the cement paste and other aggregates (granite, sand and laterite) which may be as a result of it shape and it uniform size.

viii. The SEM result also showed that the aggregates were poorly interlocked

ix. The EDX analysis showed that the concrete contained elements such as; calcium, alumina, silica, oxides, sulphur and others as shown in Table 4.7.

5.1 Recommendation

i. Laterite and PKS should be used in Civil Engineering construction works to reduce the environmental pollution and also reduce the cost of concrete and mortar production.

ii. The use of Dura and Tenera species are highly recommended for construction purposes due to the thickness of the shells.
iii. It is recommended that the PKS content in concrete should be within the range of 0% – 10% replacement of granite.
iv. It is recommended to explore the effect of chemical admixture and other additives such as super-plasticizer in other to enhance its workability and strength.

REFERENCES

ASTM C 1585. (2004). Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic Cement Concretes,.

Abdullah, A. A. (1996). Palm oil shell aggregate for lightweight concrete. , Waste Material used in concrete manufacturing, Noyes Publication , 624-636.

Adebayo, O. (2012). Assessment of palm kernel shells as aggregate in concrete and laterite blocks. Journal of Engineering Studies and Research, 88-93.

Adegbola, A., Are, L., Ashaye, T., and Komolafe, M. (1979). Agricultural Science for West African Schools and Colleges. Ibadan, Nigeria: Oxford University Press.

Adepegba, D. (1977). Structural strength of short Axially Loaded Columns of Reinforced Laterized Concrete. . Journal of Testing and Evaluation, 1-7.

Adeyemi, A. O. (2014). Compressive Strength Of Concrete And Mortar Containing Ashes As Partial Replacement For Cement, Msc thesis. Zaria: Ahmadu Bello University, Zaria.

Adoga, E. A. (2008). Durability and Fire Resistance of Laterite Rock Concrete. Department of Civil Engineering, Rivers State University of Science and Technology, Port Harcourt, Nigeria: Unpublished M.Tech Thesis.

Adzimah, S. K., and Seckley, E. (2009). Modification in the design of an already existing palmnut-fibre separator. African Journal of Environmental Science and Technology, Vol.3(11), 387-398.

Afolayan, J. (2015). Use Of Coconut Shell As Coarse Aggregate In Lightweight Concrete, Ph.D Thesis. Zaria: Ahmadu Bello University, Zaria.

Ahn, N. (2002). An Experimental Study on the Guidelines for Using Higher Contents of Aggregate Microfines in Portland Cement Concrete. Ph.D. Thesis. University of Texas at Austin.

Alawode, O., and Idowu, O. J. (2011). Effects of water cement ratios on the compressive strengthand workability of concrete and Lateritic concrete mixes. The pacific Journal of Science and Technology. Volume 12, Number 2.

Alengaram, J. U., Mahmud, H., Jamaat, M. Z., and M., S. S. (2010). Effect of aggregate size and proportion on strength properties of palm kernel shell concrete. International Journal of the Physical Sciences. Vol. 5 (12), 1848-1856.

Alengaram, U. J. (2013). Utilization of oli palm Kernel shell as lightweight aggregate in concrete-a review. Construction and BUilding Materials 38, 161-172.

Alex, A. (2015). Shear Strength Properties Of Structural Lightweight Reinforced Concrete Beams And Two-Way Slabs Using Palm Kernel Shell Coarse Aggregates. Kumasi: Kwame Nkrumah University Of Science And Technology.

Al-Khaiat, H., and Haque, M. N. (1998). Effect of internal curing on early strength and physical properties of a lightweight concrete. Cement and Concrete Research, Vol. 28(6), 859-866.

Anyawu, A., Anyawu, B., and Anyawu, V. (1982). A Textbook of Agriculture for School Certificate 4th Edition. Nsukka, Nigeria: Africana Educational Publishers Ltd.

ASTM C125-07. (2007). Standard Terminology Relating to Concrete and Concrete Aggregates. West Conshohocken, PA www.astm.org: American Standard for Testing Materials (ASTM) International,.

ASTM C330. (1999). Standard Specification for Lightweight Aggregates for Structural Concrete, . West Conshohocken, PA: American Standard for Testing Materials (ASTM) International.

Balogun, L. A., and Adepegba, D. (1982). Efeect of varying sand content in laterized concrete. International Journal of Cement and Composite and Lightweight Concrete, 235-240.

Basri, H., Mannan, M., and Zain, M. F. (1999). Concrete using oil palm shells as aggregate. Cement and Concrete Research, Vol., 29(4), 619-622.

Basri, H., Mannan, M., and Zain, M. F. (1999). Concrete using oil palm shells as aggregate. Cement and Concrete Research, Vol. 29, 619-622.

Basri, H., Mannan, M., and Zain, M. F. (1999). Concrete using oil palm shells as aggregate. Cement and Concrete Research. Vol. 29(4), 619-622.

Bhatty, J. I. (1995). Role of Minor Elements in Cement Manufacture and Use. Research and Development Bulletin RD109T, 1-35.

Bhatty, J., and Reid, K. (1989). Moderate strength concrete from lightweight sludege ash aggregate. International Journal of Cement Composites and Lightweight Concrete, Vol. 11, 179-187.

Boison, K. B. (2002). Environmental and Institutional Sustainability of Regimanuel Gray's East Airport Estate MSc. Thesis. Accra, Ghana: Royal Institute of Technology, Sweden.

Browning, J., Darwin, D., Reynolds, D., and Pendergrass, B. (2011). Lightweight aggregate as Internal curing agent to limit concrete shrinkage. Materials Journal of American Concrete Institute, Vol. 108(6), 638-644.

BS 1881: Part 102. (1983). Testing concrete: Part 102. Method for determination of slump. 2 Park Street London Wl A 2BS: British Standards Institution.

BS 8110. (1997). Structural use of concrete. 389 Chiswick High Road London W4 4AL: BSI Publications.

BS 812. (1985). Testing Aggregate - Methods for determination of particle size distribution BS 812: Part 103. 389 Chiswick High Road London W4 4AL.: British Standards Institution, BSI Publication.

BS 812. (1990). Testing Aggregate - Methods for determination of the aggregate impact value (AIV) BS 812: Part 112. 389 Chiswick High Road London W4 4AL.: British Standards Institution, BSI Publications.

BS 812. (1990). Testing Aggregates - Methods for determination of aggregate abrasion value (AAV) BS 812: Part 113. 389 Chiswick High Road London W4 4AL.: British Standards Institution, BSI Publication.

BS 812. (1990). Testing Aggregates - Methods for determination of aggregate crushing value (ACV) BS812: Part110. 389 Chiswick High Road London W4 4AL.: British Standards Institution, BSI Publications.

BS 812. (1990). Testing Aggregates - Methods for determination of moisture content, BS 812: Part 109. 389 Chiswick High Road London W4 4AL.: British Standards Institution, BSI Publication.

BS 812. (1995). Testing Aggregates - Method of determination of density BS 812: Part 2. 389 Chiswick High Road London W4 4AL: British Standards Institution, BSI Publication.

BS 812. (1995). Testing Aggregates - Methods of determination of density. 389 Chiswick High Road, London W4 4AL: British Standards Institution, BSI Publications.

BS 882. (1992). Specification for Aggregates from Natural Sources for Concrete. Chiswick High Road London: BSI Publications.

BS1881: Part 116. (1983). Testing concrete. Method for determination of compressive strength of concrete cubes. 389 Chiswick High Road London: BSI.

Cannan, T. (2003). Combined Effect of Mineral Admixtures and Curing Conditions on the Sorptivity Coefficient of Concrete. Cement and Concrete Research 33, 1637-1642.

Chandra, S., and Berntsson, L. (2002). Lightweight Aggregate Concrete, Building Material Series. Norwich, New York, U.S.A.: William Andrew Publishing.

Chen, B., and Liu, J. (2005). Contribution of hybrid fibers on the properties of the high-Strength lightweight concrete having good workability. Cement and Concrete Research, Vol., 35, 913-917.

Chen, H. J., Yen, T., Lia, T. P., and Huang, Y. (1999). Determination of the dividing strength and its relation to the concrete strength in lightweight aggregate concrete. Cement and Concrete Composites, Vol. 21, 29-37.

CIvilolgy. (2017, August 25). Lab test; Compressive Strength of concrete cubes. Retrieved from civilology : http://www.civilology.com/compressive strength of concrete cubes/

Daniel, Y. O., and Emmanuel, N. J. (2012). Experimental study on palm kernel shells as coarse Aggregates in concrete. International Journal of Scientific and Engineering research, volume 3, issue 8, 1-6.

Efe, E. I., and Salau, M. A. (2010). Effect of heat on laterized concrete. Maejo International Journal of Science and Technology. 4(1), 33-42.

Elawady, E., Hefnawy, A. A., and Ibrahim, R. A. (2014). Comparative Study on Strength, Permeability and Sorptivity ofConcrete and their relation with Concrete Durability. International Journal of Engineering and Innovative Technology (IJEIT) Volume 4, Issue 4, 133-139.

Falade, F. (1994). Influence of water/cement ratios and mix proportions on workability and characteristic strength of concrete containing laterite fine aggregate. Building and Environment, 237-240.

Gerilla, G., Teknomo, K., and Hokao, K. (2007). An environmental assessment of wood and steel reinforced concrete housing construction. Building and Environment, Vol.42, 2778-2784.

Golterman, P., Johansen, V., and Palbol, L. (1997). Packing of Aggregates: An Alternative Tool to Determine the Optimal Aggregate Mix. Materials Journal of American Concrete institute. Vol. 94(5), 435.

Graves, R. (2006). Grading, Shape, and Surface Texture, Significance of Tests and Properties of Concrete and Concrete-Making Materials. ASTM Special Technical Publication.

Gupta, B., and Gupta, A. (2004). Concrete Technology . Nai Sarak, Delhi: A.K John Publishers for standard Publishers Distributor .

Hall, C., and Yau, M. H. (1987). Water movement in porous building materials. The water absorption and sorptivity of concretes, 77-82.

Idagu, F. O., Ugama, T. I., and Ogarekpe, N. M. (2016). Compressive Strength of Laterized Concrete Using Palm Kernel as Partial Replacement of Coarse Aggregate. International Journal of Engineering Research and Technology (IJERT), 547-551.

Idagu, F. O., Ugama, T. I., and Ogarekpe, N. M. (2016). Compressive Strength of Laterized Concrete Using Palm Kernel as Partial Replacement of Coarse Aggregate. International Journal of Engineering Research and Technology (IJERT). Vol. 5 Issue 06, 547-551.

Imam, H. U., and Nura U. (2014). Compressive Strength of Concrete Using Palm Oil Nut Shell as Light Weight Aggregate. Journal of Civil Engineering and Environmental Technology (JCEET), 15.

IS 2386. (1963). Methods of test for aggregates for concrete - Specific Gravity IS 2386: Part 3. India: Bureau of Indian Standards (BIS).

IS:383:1970. (1997). Specification for coarse and fine aggregate from natural sources for concrete (second revision).

Jankovic, K., Nicolic, D., Bogovic, D., L omcar, L., and Ramacov, Z. (2011). The estimation of compresssion strength of normal and recycled aggregates concrete. Architecture and Civil Engineering, Vol. 9. No 3, 319-331.

Jonkers, H. M., Thijssen, A., Muyzer, G., Copuroglu, O., and Schlangen, E. (2010). Application of bacteria as self-healing agent for the development. Ecological Engineering 36, 230-235.

Kankam, C. K. (2000). Potential for using palm kernel shell as aggregates in Portland Cement Concrete. 25th conference on OUR WORLD INCONCRETE STRUCTURES (pp. 23-24). Singapore: Article Online id: 100025039.

Karthik, O., Haejin, K., and Colin, L. (2007). Effect of Continuous (Well-Graded) Combined Aggregate Grading on Concrete Performance Phase A: Aggregate Voids Content (Packing Density). National Ready Mix Concrete Association (NRMCA).

Kayali, O. A., and Haque, M. (1999). Status of structural lightweight concrete in Australia as the new millenium dawns. Concrete in Australia, 22-25.

Kerali, A. G. (2001). Durabilty of compressed and cement-stabilized building blocks Ph.D Thesis. Conventry, England: University of Warwick, School of Engineering, Conventry England.

Lasisi, F., and Ogunjide, A. M. (1984). Effect of grain size on the strength characteristics of cement-stabilized lateritic soils. Building and Environment. 19(1), 49-54.

Lasisi, F., and Osunade. (1985). Factors Affecting the strength and creep properties of laterized concrete. BUilding and Environment 20(2), 133-138.

Legg, F. J. (1998). Aggregates, Concrete Construction Handbook. Mc-Graw-Hill.

Lydon, F. W. (1982). Concrete Mix Design, 2nd Edition. Applied Science Publisher.

Mahmud, H., Jumaat, M. Z., and Alengaram, U. J. (2009). Influence of sand/cement ratio on mechanical properties of palm kernel shell concrete. Journal of Applied Sciences, Vol.9 , 1764-1769.

Makasa, B. (1998). Utilization and improvement of lateritic gravels in road bases. Delft, Netherland: International Institute for Aerospace survey and earth sciences (ITC).

Mannan, M. A., and Ganapathy, C. (2001). Mix design for oil palm shell concrete. Cement and Concrete Research, Vol. 31, 1323-1325.

Mannan, M., and Ganapathy, C. (2002). Engineering properties of concrete with oil palm shell as coarse aggregate. Construction and Building Materials, Vol. 16(1), 29-34.

Mehta, P. K., and Monteiro, P. J. (1993). Concrete: Structure, Properties, and Materials. New Jersey: Prentice-Hall.

Mehta, P. K., and Monteiro, P. J. (1993). Concrete: Structure, Properties, and Materials, Second Edition. Englewood Cliffs, New Jersey: Prentice-Hall.

Moriconi, G. (2007). Recyclable Materials in Concrete Technology: Sutainability and Durability. Ancona, Italy: Department of MAterials and Environmental Enigineering and Physics, Universita Politecnica delle Marche.

Ndoke, P. N. (2006). Performance of palm kernel shells as a partial replacement for coarse aggregate in asphalt concrete. Leonardo Electronic Journal of Practices and Technologies , 145-152.

Nevelle, G. B. (2012). Concrete Manual. INternational Code Council.

Neville, A. (1997). Aggregate bond and modulus of elasticity of concrete. Material Journal of American Concrete Institute. Vol. 94, 71-74.

Neville, A. M. (1981). Properties of Concrete, Third edition. Harlow: Longman Scientific and Technical.

Neville, A. M., and Brooks, J. J. (2008). Concrete Technology. Harlow, Essex: Pearson Education Limited.

Nicolas, B., Gilles, P.-C., and Noel, D. (2001). Experimental analysis of compaction of concrete and mortar. International Journal For Numerical and Analytical Methods In Geomechanics, 1467-1486.

O'Flynn, M. L. (2000). Manufactured Sands from Hardrock Quarries: Environmental Solution or Dilemma for Southeast Queensland. Australian Journal of Earth Sciences. Vol. 47, 65-73.

Okafor, F. O. (1988). Palm kernel shell as a lightweight aggregate for concrete. Cement and Concrete Research, Vol. 18(6), 901-910.

Okpala, D. C. (1990). Palm kernel shell as a lightweight aggregate in concrete. Building Environment, Vol. 25(4), 291-296.

Olugbenga, A., Kolapo, O., Oludare, O., and Abiodun, O. (2007). A study of compressive strength characteristics of laterite/sand hollow blocks. Civil Engineering Dimension, 26-29.

Olutoge, F. A. (2010). Investigations on Sawdust and Palm Kernel Shells as Aggregate Replacement. Asian Research Publishing Network (ARPN) Journal of Engineering and Applied Sciences, Vol. 5(4), 7-13.

Opeke, L. (1987). Tropical Tree Crops. Ilorin pp 252-266: Woye and Sons (Nig) Limited .

Orchard, D. (1979). Concrete Technology fourth edition. London: Applied Science Publishers.

Osadebe, N. N., and Nwakonobi, T. U. (2007). Structural Characteristics of Laterized Concrete at Optimum Mix proprtion. Nigerian Journal of Technology, 12-17.

Osunade, J. A. (2002). Effect of replacement of lateritic soils with granite fines on the compressive and tensile strengths of laterized concrete. Building and Environment, 491-496.

Owens, P. L. (1993). Lightweight aggregates for structural concrete. In J. L. Edited Clarke, Structural lightweight Aggregate Concrete (pp. 1-9). Glasgow,London: Blackie Academic and Professional.

Owolabi, A. (2012). Assessment Of Palm Kernel Shells As Aggregate In Concrete And Laterite Blocks. Journal of Engineering Studies and Research – Volume 18 , 88-93.

OWOLABI, A. (2012). ASSESSMENT OF PALM KERNEL SHELLS AS AGGREGATE IN CONCRETE AND LATERITE BLOCKS. Journal of Engineering Studies and Research – Volume 18 , 88-93.

Patel, V. N. (2009). SORPTIVITY TESTING TO ASSESS DURABILITY OF CONCRETE AGAINST FREEZE-THAW CYCLING. Montreal: The Department of Civil Engineering and Applied Mechanics, McGill University, Montreal, Canada.

Pitroda, J., and Umrigar, D. F. (2013). Evaluation of Sorptivity and Water Absorption of Concrete with Partial Replacement of Cement by Thermal Industry Waste (Fly Ash). International Journal of Engineering and Innovative Technology (IJEIT), Volume 2, Issue 7, , 245-249.

Popovics, S. (1992). Concrete Materials Properties, Specifications and Testing, 2nd Edition. New Jersey, USA.: Noyes Publications .

Quiroga, P. N., and Fowler, W. D. (2004). The effects of aggregates characteristics on the performance of Portland cement concrete. Austin, USA .

Rached, M., Moya, D. M., and Fowler, D. (2009). Utilizing Aggregates Characteristics to Minimize Cement Content in Portland Cement Concrete. Austin USA: International Center for Aggregates Research (ICAR 401).

Rossignolo, J. A., Agnesini, M., and Morais, J. A. (2003). Properties of high-performance LWC for precast structures with Brazilian lightweight aggregates. Cement and Concrete composites, Vol. 25, 77-82.

Sabir, B. B., Wild, S., and O'Farrell, M. (1998). A water sorptivity test for mortar and concrete. Materials and Structures/Materiaux et Constructions, Vol. 31, 568-574.

Salau, M. A. (2008). Abundant Local Structural Engineering Materials without Affordable Structures. Lagos: University of Lagos Press.

Salau, M. A., and Balogun, L. A. (1998). Shrinkage deformations of laterized concrete. Buildng and Environment, 165-173.

Saynor, M., and Harford, A. (2010). Pilot study on the seperation and physical characterisation of laterite material from the Ranger project area. Darwin, Australia: Ssd Publications.

Shafigh, P., Jumaat, M., and Mahmud, H. (2010). Mix design and mechanical properties of oil palm shell lightweight aggregate concrete. International Journal of the Physical Sciences. Vol. 5(14), 2127-2134.

Shafigh, P., Jumaat, Z. M., and Mahmud, H. (2010). Mix design and mechanical properties of oil palm shell lightweight aggregate concrete. International Journal of the Physical Sciences, Vol. 5(14), 2127-2134.

Shetty, M. S. (2005). Concrete technology theory and practice. India: S Chand and Company Ltd., India. .

Shetty, M. S. (2015). Concrete Technology. Ram Nagar, New Delhi: S. Chand Pvt. Ltd.

Shilstone, J. M. (1990). Concrete Mixture Optimization. Concrete International: Design and Construction. Vol 12, 33-39.

Shodhganga. (2017, November 07). Retrieved from Inflibnet: http://shodhganga.inflibnet.ac.in/bitstream/10603/22950/12/12_chapter7.pdf

Short, A., and Kinniburgh, W. (1978). Lightweight Concrete 3rd Ed. Great Yormouth, Great Britain: Galliard Printers.

Sundram, K., Ravigadevi, S., and Yew-Ai, T. (2003). Palm fruit chemistry and nutrition. Asia Pacific Journal ofClinical Nutrition, Vol., 12(3), 355-362.

Sustainable Concrete. (2017, May 30). Sustainable Concrete. Retrieved from Sustainable Concrete: http://www.sustainableconcrete.org.uk

Teo, D. C., Mannan, M. A., and Kurian, V. J. (2006). Structural Concrete Using Oil Palm Shell (OPS) as Lightweight Aggregate. Turkish Journal of Engineering and Environmental Science, Vol. 30, 1-7.

Teo, D., Mannan, M., Kurian, V., and Ganapathy, C. (2007). Lightweight concrete made from oil palm shell (OPS): Structural bond and durability properties. Building and Environment, Vol. 42(7), 2614-2621.

Udoeyo, F. F., Brooks, R., Udo-Inyang, P., and Canice, I. (2010). Residual compressive strength of laterized concrete subjected to elevated temperatures. Research Journal of Applied Sciences, Engineering and Technology 2(3), 262-267.

Udoeyo, F. F., Brooks, R., Utam, C., Udo-Inyang, P., and Ukpong, E. C. (2010). Effect of non-standard curing methods on the compressive strength of laterized Concrete. ARPN Journal of Engineering and Applied Science 5(2), 6-20.

Udoeyo, F. F., Iron, U. H., and Odim, O. O. (2006). Strength performance of laterized concrete. Construction and Building Materials. 20(10), 1057-1062.

Washa, G. W. (1998). Permeability and Absorption, Concrete Construction Handbook. New York: McGraw-Hill 4th edition.

Williams, F., Ijigah, E., Anum, I. I., and Obanibi, A. (2014). Suitability of Palm Kernel Shell As Coarse Aggregate In Lightweight Concrete Production. Civil and Environmental Research, 55-59.

Worrell, E., Price, L., Martin, N., Hendriks, C., and Ozawa Meida, L. (2001). Carbon dioxide emissions from the global cement industry. Annual Review of Energy and the Environment, Vol. 26, 303-329.

Yaqub, M., and Bukhari, I. (2006). Effect of size of coarse aggregate on compressive strength of high strength concretes. Our world in Concrete and Structures. Singapore: Available online: http://cipremier.com/100031052.

Zami, M. S., and Lee, A. (2008). Using earth as a building material for sustainable low cost. The Built and Human Environment Review, Vol 1, 40-45.

Zarina Itam, Nur, L. M., Md Ashraful, A., and Usama, I. A. (2016). The Feasibility of Palm Kernel Shell as a Replacement for Coarse Aggregate in Lightweight

Concrete. International Conference on Advances in Renewable Energy and Technologies (ICARET 2016) (pp. 1-4). Malaysia: IOP Publishing.

Zawde, B. (1983). Compressive strength of mortar in hot-humid environment. Strength, Mortars, Hot-Climate, HIgh Humidity Vol 13, No.2, 225-232.

Zayed, A., Brown, K., and Hanhan, A. (2004). Effect of Sulfur trioxide content on concrete structures using Florida materials. Florida, USA: Florida Department of Transportation.

APPENDICE

Appendix A: Material Estimation and Mix Proportion

Table A1: Material Estimation for both the (150mm × 150mm and the 100mm × 100mm) Cubes

<table>
<tr><th>150mm × 150mm cubes</th><th colspan="2">100mm × 100mm cubes</th></tr>
<tr><td rowspan="2">Density of concrete = 2400 kg/m^3
Mix ratio = 1 : 2 : 4
Volume of one cube = 0.003375m^3
Volume of 3 cubes = 3 × 0.003375 = 0.012m^3
Weight of a mix (3 Cubes) = 2400 × 0.012 = 28.8kg
Cement = $\frac{1}{7} \times 28.8 = 4.11kg$
Sand = $\frac{2}{7} \times 28.8 = 8.23\ kg$
Gravel = $\frac{4}{7} \times 28.8 = 16.46\ kg$</td><td colspan="2">Density of concrete = 2400 kg/m^3
Mix ratio = 1 : 2 : 4
Volume of one cube = 0.001m^3</td></tr>
<tr><td>Volume of 2 cubes = 2 × 0.001 = 0.002 m^3
Weight of a mix (2 Cubes) = 2400 × 0.002 = 4.8 kg
Cement = $\frac{1}{7} \times 4.8 = 0.68\ kg$
Sand = $\frac{2}{7} \times 4.8 = 1.37\ kg$
Gravel = $\frac{4}{7} \times 4.8 = 2.74\ kg$</td><td>Volume of 1 cube = 0.001 m^3
Weight of a mix (1 Cube) = 2400 × 0.001 = 2.4 kg
Cement = $\frac{1}{7} \times 2.4 = 0.34\ kg$
Sand = $\frac{2}{7} \times 2.4 = 0.69\ kg$
Gravel = $\frac{4}{7} \times 2.4 = 1.37\ kg$</td></tr>
</table>

Table A2: Mix proportion

MIX	CEMENT (KG)	WATER (KG) For W/C ratio of 0.5	FINE AGGREGATE		COARSE AGGREGATE	
			LATERITE (KG)	SAND (KG)	PKS (KG)	GRAVEL (KG)
CONTROL	4.11	2.06	0	8.23	0	16.46
0% PKS (2)	4.79	2.40	2.88	6.72	0	19.20
10% PKS (2)	4.79	2.40	2.88	6.72	1.92	17.28
20% PKS (2)	4.79	2.40	2.88	6.72	3.84	15.36
30% PKS (1)	4.45	2.23	2.67	6.24	5.35	12.48
40% PKS (1)	4.45	2.23	2.67	6.24	7.13	10.70
50% PKS (1)	4.45	2.23	2.67	6.24	8.92	8.92
TOTAL	31.83	15.95	16.65	47.11	27.16	100.4

Appendix B: Mechanical and Physical Test Result of Aggregate Samples

Appendix B1: Sieve analysis result and calculation

Table B1.1: Sieve Analysis of Granite Aggregate

SIEVE OPENING	WEIGHT OF SOIL RETAINED (g)	PERCENTAGE OF SOIL RETAINED	CUMULATIVE PERCENTAGE RETAINED	PERCENTAGE PASSING
40	0	0	0	100
20	240	24	24	76
10	450	45	69	31
5	220	22	91	9
2	70	7	98	2
0.5	0	0	98	2
0.25	5	0.50	98.50	1.50
0.075	10	1	99.50	0.50
PAN	5	0.50	100	0

Table B1.2: Sieve Analysis of Palm Kernel Shell Aggregate (PKS)

SIEVE OPENING	WEIGHT OF SOIL RETAINED (g)	PERCENTAGE OF SOIL RETAINED	CUMULATIVE PERCENTAGE RETAINED	PERCENTAGE FINER
40	0	0	0	100
20	0	0	0	100
10	690	69	69	31
5	250	25	94	6
2	55	5.5	99.50	0.50
0.5	0	0	99.50	0.50
0.25	0	0	99.50	0.50
0.075	5	0.5	100	0

PAN	0	0	100	0

Table B1.3: Sieve Analysis of Sand Aggregate

SIEVE OPENING	WEIGHT OF SOIL RETAINED (g)	PERCENTAGE OF SOIL RETAINED	CUMULATIVE PERCENTAGE RETAINED	PERCENTAGE FINER
40	0	0	0	100
20	0	0	0	100
10	0	0	0	100
5	30	3	3	97
2	155	15.5	18.5	81.5
0.5	560	56	74.5	25.5
0.25	200	20	94.5	5.5
0.075	50	5	99.5	0.50
PAN	5	0.5	100	0

Table B1.4: Sieve Analysis of Laterite Aggregate

SIEVE OPENING	WEIGHT OF SOIL RETAINED (g)	PERCENTAGE OF SOIL RETAINED	CUMULATIVE PERCENTAGE RETAINED	PERCENTAGE FINER
40	0	0	0	100
20	0	0	0	100
10	5	1	1	99
5	30	6	7	93
2	115	23	30	70
0.5	160	32	62	38
0.25	90	18	80	20
0.075	80	16	96	4
PAN	20	4	100	0

Appendix B2: Sieve analysis calculation

Where

$$C_u = \frac{D_{60}}{D_{10}}$$

$C_u < 5$ ----- connotes a Very Uniform Soil

$C_u = 5$ ----- Medium Uniform Soil

$C_u > 5$ ----- Non-uniform Soil

Also,

$$C_g = \frac{{D_{30}}^2}{D_{60} \times D_{10}}$$

C_g from 1 to 3 ------- indicates a well graded soil

GRANITE

Coefficient of Uniformity (Cu) = $\frac{D_{60}}{D_{10}} = \frac{16}{5.25} = 3.05$

Coefficient of curvature/ gradation (Cg) = $\frac{{D_{30}}^2}{D_{60} \times D_{10}} = \frac{9.6^2}{16 \times 5.25} = 1.10$

Thus, **Granite** is uniform and well graded.

PALM KERNEL SHELL

Coefficient of Uniformity (Cu) = $\frac{D_{60}}{D_{10}} = \frac{14}{6} = 2.33$

Coefficient of curvature/ gradation (Cg) = $\frac{{D_{30}}^2}{D_{60} \times D_{10}} = \frac{9.9^2}{14 \times 6} = 1.167$

Thus, **PKS** is uniform and well graded.

SAND

Coefficient of Uniformity (Cu) = $\frac{D_{60}}{D_{10}} = \frac{1.3}{0.315} = 4.13$

Coefficient of curvature/ gradation (Cg) = $\frac{{D_{30}}^2}{D_{60} \times D_{10}} = \frac{0.57^2}{1.3 \times 0.315} = 0.79$

Thus, **Sand** is uniform and well graded.

LATERITE

Coefficient of Uniformity (Cu) = $\frac{D_{60}}{D_{10}} = \frac{1.35}{0.15} = 9$

Coefficient of curvature/ gradation (Cg) = $\frac{{D_{30}}^2}{D_{60} \times D_{10}} = \frac{0.37^2}{1.35 \times 0.15} = 0.676$

Thus, **Laterite** is non uniform and poorly graded.

Appendix B3: Specific gravity result

Table B3.1: Specific gravity result for Granite aggregate

Test Description	Granite	
Trials	A	B
Empty weight of Pycnometer	377.03	395.12
Empty + Specimen	541.99	584.65
Empty + Specimen + Water	742.95	766.65
Empty + Water	639.00	644.83
Specific Gravity	2.70	2.80
Average Specific Gravity	2.75	

Table B3.2: Specific gravity result for sand aggregate

Test Description	Sand (g)	
Trials	A	B
Empty weight of Pycnometer	24.84	23.57
Empty + Specimen	60.42	64.57
Empty + Specimen + Water	101.04	100.83
Empty + Water	77.70	75.45
Specific Gravity	2.91	2.62
Average Specific Gravity	2.77	

Table B3.3: Specific Gravity result for laterite aggregate

Test Description	Laterite (g)	
Trials	A	B
Empty weight of Pycnometer	26.42	24.68

Empty + Specimen	54.80	56.63
Empty + Specimen + Water	93.56	94.40
Empty + Water	79.32	76.10
Specific Gravity	2.01	2.34
Average Specific Gravity	2.18	

Table B3.4: Specific gravity result for PKS aggregate

Test Description	Palm Kernel Shell (PKS)	
Trials	A	B
Empty weight of Pycnometer	389.08	388.85
Empty + Specimen	450.56	441.43
Empty + Specimen + Water	655.83	658.54
Empty + Water	647.14	640.90
Specific Gravity	1.16	1.50
Average Specific Gravity	1.33	

Appendix B4: Porosity test result

Table B4.1: Porosity test result for coarse aggregate

Specimen	PKS (mL)	Granite (mL)
Volume of sample (V_1)	200	200
Volume of water	200	200
Volume of sample + water (V_2)	340	330
Volume of sample + water (Soaked) (V_3)	320	325
Porosity = $(\frac{v2-v3}{v2}) \times 100$	5.88	1.52

Appendix B5: Moisture content test result

Table B5.1: Moisture Content of Sand

Specimen	Sand (g)	
Container Number	1	2
Container weight (W_1)	23.75	19.60
Container + sample (W_2)	57.98	61.15
Container + dry sample(W_3)	57.23	61.13
Moisture content = $\frac{W2-W3}{w3-w1} \times 100$	2.24	0.048
Average moisture content	1.14 %	

Table A5.2: Moisture content of Laterite

Specimen	Laterite (g)	
Container Number	3	4
Container weight (W_1)	26.62	18.25
Container + sample (W_2)	67.18	52.81
Container + dry sample(W_3)	66.04	51.67
Moisture content = $\frac{W2-W3}{w3-w1} \times 100$	2.89	3.41
Average moisture content	3.15 %	

Table B5.3: Moisture Content of PKS

Specimen	PKS (g)	
Container Number	5	6
Container weight (W_1)	20.02	13.50
Container + sample (W_2)	51.15	44.83
Container + dry sample(W_3)	50.98	44.63
Moisture content = $\frac{W2-W3}{w3-w1} \times 100$	0.549	0.642
Average moisture content	0.60 %	

Table B5.4: Moisture Content of Granite

Specimen	Granite (g)	
Container Number	7	8
Container weight (W_1)	19.76	26.45
Container + sample (W_2)	74.28	87.37
Container + dry sample(W_3)	74.27	87,37
Moisture content = $\frac{W2-W3}{w3-w1} \times 100$	0.018	0
Average moisture content	0.01 %	

Appendix B6: Loose bulk density

Table B6.1: Bulk density of aggregate samples

Test description	Gravel	Sand	PKS	Laterite
Weight of sample (W) (g)	365.19	500.00	218.00	365.80
Volume of sample (V) (ml)	220.00	280.00	330.00	300.00
Bulk density = $\frac{W}{V}$ (kg/m^3)	1660	1786	661	1220

Appendix B7: Water absorption test result

Table B7.1: Water absorption of aggregate samples

Test description	PKS	Granite
Dry weight (W1) (g)	500	4900
Wet weight (W2) (g)	525	5000
Water Absorption = $\frac{W2-W1}{w1} \times 100$	5%	2.04%

Appendix B8: Aggregate crushing value test result

Table B8.1: Aggregate Crushing Value of PKS and Granite aggregate.

Test Description	PKS	Granite
Initial weight of dry sample (W1)	1000.00	1000.00
Final weight of dry sample (W2)	968.78	853.50
Weight of sample passing 2.36mm test sieve (W3)	31.22	146.50
Aggregate Crushing Value = $\frac{W3}{W1} \times 100$	3.12%	14.65%

Appendix B9: Aggregate abrasion test result

Table B9.1: Aggregate Abrasion test result

Test description	PKS (g)		Granite (g)	
Trial	1	2	1	2
Initial weight of dry sample (W1)	595	590	5100	5050
Final weight of dry sample (W2)	590	585	5000	4950
Abrasion value = $\frac{W1-W2}{W1} \times 100$	0.84	0.85	1.96	1.98
Average Abrasion value	0.85		1.97	

Appendix B10: Aggregate impact value test result

Table B10.1: Aggregate Impact Value of coarse aggregates.

Test Aggregate	PKS (g)	Granite (g)
Total weight of dry sample (W1)	5100	498
Weight of portion passing 2.36mm test sieve (W2)	50	3
Aggregate impact Value = $\frac{W2}{W1} \times 100$	0.98%	0.60%

Appendix C: Workability Test Results

Table C1: Slump Test of Fresh Concrete Mix: (Mix Ratio: 1:2:4, W/C: 0.5)

Sample Mix	Height of cone (mm) A	Height of concrete (mm) B	Slump (mm) A-B	Workability
Control	300	290	10	Very low
0% PKS	300	294	6	Very low
10% PKS	300	300	0	Very low
20% PKS	300	300	0	Very low
30% PKS	300	300	0	Very low
40% PKS	300	300	0	Very low
50% PKS	300	300	0	Very low

Appendix D: Compressive Strength Test and Density of Hardened Concrete Cubes

(Mix Ratio: 1:2:4, W/C: 0.50) to (BS 1881: Part 108: 1983)

Table D1: Compressive Strength and Density of Control Concrete

CURING AGE (DAYS)	CUBE NO	L(mm)	B (mm)	T (mm)	AREA A (mm^2)	VOLUME V (m^3) $\times 10^{-3}$	WEIGHT W (Kg)	DENSITY = W/V (Kg/m^3)	LOAD P (KN)	COMPRESSIVE STRENGTH (N/mm2)
7 DAYS	1	150	150	150	22500	3.3750	8.02	2376.30	358.53	15.93
	2	150	150	150	22500	3.3750	7.96	2358.52	370.88	16.48
	3	150	150	150	22500	3.3750	8.27	2450.37	349.8	15.55
	AVERAGE	150	150	150	22500	3.3750	8.08	2395.14	359.74	15.99
14 DAYS	1	150	150	150	22500	3.3750	8.15	2414.81	364.26	16.19
	2	150	150	150	22500	3.3750	8.15	2414.81	396.72	17.63
	3	150	150	150	22500	3.3750	8.20	2429.63	370.88	16.48
	AVERAGE	150	150	150	22500	3.3750	8.17	2419.75	377.29	16.77
21 DAYS	1	150	150	150	22500	3.3750	8.14	2411.85	495.00	22.00
	2	150	150	150	22500	3.3750	8.14	2411.85	490.10	21.78
	3	150	150	150	22500	3.3750	8.27	2450.37	502.00	22.31

	AVERAGE	150	150	150	22500	3.3750	8.18	2424.69	495.7	22.03
28 DAYS	1	150	150	150	22500	3.3750	8.43	2497.78	558.45	24.82
	2	150	150	150	22500	3.3750	8.61	2551.11	559.45	24.42
	3	150	150	150	22500	3.3750	8.46	2506.67	567.45	25.22
	AVERAGE	150	150	150	22500	3.3750	8.50	2518.31	558.50	24.82
60 DAYS	1	150	150	150	22500	3.3750	8.17	2420.74	517.50	23.00
	2	150	150	150	22500	3.3750	8.23	2438.52	520.20	23.12
	3	150	150	150	22500	3.3750	8.59	2545.19	529.70	23.54
	AVERAGE	150	150	150	22500	3.3750	8.33	2469.18	522.50	23.22
90 DAYS	1	150	150	150	22500	3.3750	8.30	2459.26	517.30	22.99
	2	150	150	150	22500	3.3750	8.40	2488.89	538.40	23.96
	3	150	150	150	22500	3.3750	8.50	2518.52	550.80	24.48
	AVERAGE	150	150	150	22500	3.3750	8.40	2488.18	535.70	23.81

Table D2: Compressive Strength and Density of 0% PKS Concrete

CURING AGE (DAYS)	CUBE NO	L(mm)	B (mm)	T (mm)	AREA A (mm^2)	VOLUME V (m^3) $\times 10^{-3}$	WEIGHT W (Kg)	DENSITY = W/V (Kg/m^3)	LOAD P (KN)	COMPRESSIVE STRENGTH (N/mm2)

7 DAYS	1	150	150	150	22500	3.3750	8.50	2518.52	284.43	12.64
	2	150	150	150	22500	3.3750	8.20	2429.63	320.72	14.25
	3	150	150	150	22500	3.3750	9.00	2666.67	289.36	12.86
	AVERAGE	150	150	150	22500	3.3750	7.44	2204.94	298.13	13.25
14 DAYS	1	150	150	150	22500	3.3750	8.30	2509.45	300.15	13.34
	2	150	150	150	22500	3.3750	8.20	2479.21	305.14	13.56
	3	150	150	150	22500	3.3750	8.10	2448.98	291.32	12.96
	AVERAGE	150	150	150	22500	3.3750	8.20	2479.21	299.03	13.29
21 DAYS	1	150	150	150	22500	3.3750	8.50	2518.52	437.63	19.45
	2	150	150	150	22500	3.3750	8.10	2400.00	441.00	19.60
	3	150	150	150	22500	3.3750	8.20	2429.63	434.25	19.30
	AVERAGE	150	150	150	22500	3.3750	8.27	2449.38	437.63	19.45
28 DAYS	1	150	150	150	22500	3.3750	8.20	2479.21	453.38	20.15
	2	150	150	150	22500	3.3750	8.30	2509.45	452.25	20.10
	3	150	150	150	22500	3.3750	8.20	2479.21	455.18	20.23
	AVERAGE	150	150	150	22500	3.3750	8.23	2489.29	453.60	20.16
60 DAYS	1	150	150	150	22500	3.3750	8.06	2388.15	477.68	21.23
	2	150	150	150	22500	3.3750	8.06	2388.15	473.40	21.04
	3	150	150	150	22500	3.3750	8.18	2423.70	459.00	20.4

	AVERAGE	150	150	150	22500	3.3750	8.10	2399.39	470.03	20.89
90 DAYS	1	150	150	150	22500	3.3750	8.08	2394.07	443.03	19.69
	2	150	150	150	22500	3.3750	7.99	2367.41	453.38	20.15
	3	150	150	150	22500	3.3750	8.17	2420.74	460.35	20.46
	AVERAGE	150	150	150	22500	3.3750	8.08	2395.41	452.25	20.1

Table D3: Compressive Strength and Density of 10% PKS Concrete

CURING AGE (DAYS)	CUBE NO	L(mm)	B (mm)	T (mm)	AREA A (mm^2)	VOLUME V (m^3) $\times 10^{-3}$	WEIGHT W (Kg)	DENSITY = W/V (Kg/m^3)	LOAD P (KN)	COMPRESSIVE STRENGTH (N/mm2)
7 DAYS	1	150	150	150	22500	3.3750	7.52	2228.15	271.32	12.06
	2	150	150	150	22500	3.3750	7.35	2177.78	277.02	12.31
	3	150	150	150	22500	3.3750	7.60	2251.85	269.14	11.96
	AVERAGE	150	150	150	22500	3.3750	7.49	2219.26	272.48	12.11
14 DAYS	1	150	150	150	22500	3.3750	8.00	2418.75	293.32	13.04
	2	150	150	150	22500	3.3750	7.60	2297.81	279.85	12.44
	3	150	150	150	22500	3.3750	7.80	2358.28	291.25	12.94
	AVERAGE	150	150	150	22500	3.3750	7.80	2351.28	288.23	12.81

21 DAYS	1	150	150	150	22500	3.3750	7.90	2340.74	318.83	14.17
	2	150	150	150	22500	3.3750	8.00	2370.37	368.33	16.37
	3	150	150	150	22500	3.3750	8.00	2370.37	336.83	14.97
	AVERAGE	150	150	150	22500	3.3750	7.97	2360.49	341.33	15.17
28 DAYS	1	150	150	150	22500	3.3750	8.10	2448.98	382.50	17.00
	2	150	150	150	22500	3.3750	7.90	2388.51	368.78	16.39
	3	150	150	150	22500	3.3750	8.00	2418.75	355.05	15.78
	AVERAGE	150	150	150	22500	3.3750	8.00	2418.75	368.78	16.39
60 DAYS	1	150	150	150	22500	3.3750	7.45	2207.41	314.78	13.99
	2	150	150	150	22500	3.3750	7.90	2340.61	348.98	15.51
	3	150	150	150	22500	3.3750	8.35	2474.07	349.43	15.53
	AVERAGE	150	150	150	22500	3.3750	7.90	2340.61	337.73	15.01
90 DAYS	1	150	150	150	22500	3.3750	7.51	2225.19	317.03	14.09
	2	150	150	150	22500	3.3750	7.67	2272.59	328.28	14.59
	3	150	150	150	22500	3.3750	8.43	2497.78	359.78	15.99
	AVERAGE	150	150	150	22500	3.3750	7.87	2330.69	335.03	14.89

Table D4: Compressive Strength and Density of 20% PKS Concrete

CURING AGE (DAYS)	CUBE NO	L(mm)	B (mm)	T (mm)	AREA A (mm^2)	VOLUME V (m^3) $\times 10^{-3}$	WEIGHT W (Kg)	DENSITY = W/V (Kg/m^3)	LOAD P (KN)	COMPRESSIVE STRENGTH (N/mm2)
7 DAYS	1	150	150	150	22500	3.3750	6.60	1955.56	183.89	8.17
	2	150	150	150	22500	3.3750	6.20	1837.04	188.48	8.38
	3	150	150	150	22500	3.3750	6.40	1896.30	186.39	8.28
	AVERAGE	150	150	150	22500	3.3750	6.40	1896.30	186.39	8.28
14 DAYS	1	150	150	150	22500	3.3750	6.60	1995.46	200.01	8.89
	2	150	150	150	22500	3.3750	6.50	1965.23	191.10	8.49
	3	150	150	150	22500	3.3750	6.50	1965.23	189.55	8.42
	AVERAGE	150	150	150	22500	3.3750	6.53	1975.31	193.50	8.60
21 DAYS	1	150	150	150	22500	3.3750	7.50	2221.85	246.15	10.94
	2	150	150	150	22500	3.3750	7.47	2212.22	230.40	10.24
	3	150	150	150	22500	3.3750	7.48	2215.94	221.40	9.84
	AVERAGE	150	150	150	22500	3.3750	7.48	2216.67	232.65	10.34
28 DAYS	1	150	150	150	22500	3.3750	7.50	2267.57	264.38	11.75
	2	150	150	150	22500	3.3750	7.40	2237:34	223.43	9.93

	3	150	150	150	22500	3.3750	7.20	2176.87	243.9	10.84
	AVERAGE	150	150	150	22500	3.3750	7.37	2227.26	243.9	10.84
60 DAYS	1	150	150	150	22500	3.3750	7.39	2189.63	225.00	10.00
	2	150	150	150	22500	3.3750	7.54	2234.07	202.28	8.99
	3	150	150	150	22500	3.3750	7.36	2180.74	228.83	10.17
	AVERAGE	150	150	150	22500	3.3750	7.43	2200.94	218.70	9.72
90 DAYS	1	150	150	150	22500	3.3750	7.17	2124.44	223.43	9.93
	2	150	150	150	22500	3.3750	7.34	2174.81	216.90	9.64
	3	150	150	150	22500	3.3750	7.69	2278.52	202.23	8.99
	AVERAGE	150	150	150	22500	3.3750	7.40	2192.09	214.20	9.52

Table D5: Compressive Strength and Density of 30% PKS Concrete

CURING AGE (DAYS)	CUBE NO	L(mm)	B (mm)	T (mm)	AREA A (mm^2)	VOLUME V (m^3) $\times10^{-3}$	WEIGHT W (Kg)	DENSITY = W/V (Kg/m^3)	LOAD P (KN)	COMPRESSIVE STRENGTH (N/mm2)
7 DAYS	1	150	150	150	22500	3.3750	6.15	1822.22	129.87	5.77
	2	150	150	150	22500	3.3750	5.80	1718.52	134.55	5.98
	3	150	150	150	22500	3.3750	6.20	1837.04	138.02	6.13

	AVERAGE	150	150	150	22500	3.3750	6.05	1792.59	134.10	5.96
14 DAYS	1	150	150	150	22500	3.3750	7.00	2116.40	163.61	7.27
	2	150	150	150	22500	3.3750	6.70	2025.70	161.27	7.17
	3	150	150	150	22500	3.3750	6.60	1995.46	159.92	7.11
	AVERAGE	150	150	150	22500	3.3750	6.77	2045.05	161.55	7.18
21 DAYS	1	150	150	150	22500	3.3750	6.55	1940.74	184.95	8.22
	2	150	150	150	22500	3.3750	7.00	2074.07	197.78	8.79
	3	150	150	150	22500	3.3750	6.60	1955.56	193.73	8.61
	AVERAGE	150	150	150	22500	3.3750	6.72	1990.12	192.15	8.54
28 DAYS	1	150	150	150	22500	3.3750	6.66	2013.61	203.18	9.03
	2	150	150	150	22500	3.3750	6.70	2025.70	202.28	8.99
	3	150	150	150	22500	3.3750	6.70	2025.70	235.13	10.45
	AVERAGE	150	150	150	22500	3.3750	6.69	2021.67	213.53	9.49
60 DAYS	1	150	150	150	22500	3.3750	6.28	1860.74	225.23	10.01
	2	150	150	150	22500	3.3750	6.59	1952.59	202.28	8.99
	3	150	150	150	22500	3.3750	7.14	2115.56	180.68	8.03
	AVERAGE	150	150	150	22500	3.3750	6.67	1976.41	202.73	9.01
90 DAYS	1	150	150	150	22500	3.3750	6.41	1899.26	213.53	9.49
	2	150	150	150	22500	3.3750	6.66	1973.33	184.95	8.22

	3	150	150	150	22500	3.3750	6.67	1976.30	194.85	8.66
	AVERAGE	150	150	150	22500	3.3750	6.58	1950.61	197.78	8.79

Table D6: Compressive Strength and Density of 40% PKS Concrete

CURING AGE (DAYS)	CUBE NO	L(mm)	B (mm)	T (mm)	AREA A (mm^2)	VOLUME V (m^3) $\times 10^{-3}$	WEIGHT W (Kg)	DENSITY = W/V (Kg/m^3)	LOAD P (KN)	COMPRESSIVE STRENGTH (N/mm2)
7 DAYS	1	150	150	150	22500	3.3750	6.20	1837.04	108.42	4.82
	2	150	150	150	22500	3.3750	6.10	1807.41	114.66	5.10
	3	150	150	150	22500	3.3750	6.35	1881.48	112.21	4.99
	AVERAGE	150	150	150	22500	3.3750	6.22	1841.98	111.83	4.97
14 DAYS	1	150	150	150	22500	3.3750	6.50	1965.23	136.52	6.07
	2	150	150	150	22500	3.3750	6.10	1844.29	123.81	5.50
	3	150	150	150	22500	3.3750	6.50	1965.23	132.83	5.90
	AVERAGE	150	150	150	22500	3.3750	6.37	1924.92	131.03	5.82
21 DAYS	1	150	150	150	22500	3.3750	6.40	1896.30	157.50	7.00
	2	150	150	150	22500	3.3750	6.60	1955.56	180.00	8.00
	3	150	150	150	22500	3.3750	6.40	1896.30	170.78	7.59

	AVERAGE	150	150	150	22500	3.3750	6.63	1965.43	169.43	7.53
28 DAYS	1	150	150	150	22500	3.3750	6.50	1965.23	211.05	9.38
	2	150	150	150	22500	3.3750	6.80	2055.93	203.40	9.04
	3	150	150	150	22500	3.3750	6.80	2055.93	197.10	8.76
	AVERAGE	150	150	150	22500	3.3750	6.70	2025.70	203.85	9.06
60 DAYS	1	150	150	150	22500	3.3750	6.93	2053.33	196.88	8.75
	2	150	150	150	22500	3.3750	6.68	1979.26	200.48	8.91
	3	150	150	150	22500	3.3750	6.61	1958.52	200.03	8.89
	AVERAGE	150	150	150	22500	3.3750	6.74	1996.14	199.13	8.85
90 DAYS	1	150	150	150	22500	3.3750	6.59	1952.59	191.03	8.49
	2	150	150	150	22500	3.3750	6.30	1866.67	194.40	8.64
	3	150	150	150	22500	3.3750	6.67	1976.30	196.42	8.73
	AVERAGE	150	150	150	22500	3.3750	6.52	1932.47	193.95	8.62

Table D7: Compressive Strength and Density of 50% PKS Concrete

CURING AGE (DAYS)	CUBE NO	L(mm)	B (mm)	T (mm)	AREA A (mm^2)	VOLUME V (m^3) $\times 10^{-3}$	WEIGHT W (Kg)	DENSITY = W/V (Kg/m^3)	LOAD P (KN)	COMPRESSIVE STRENGTH (N/mm2)

7 DAYS	1	150	150	150	22500	3.3750	5.90	1748.15	107.55	4.78
	2	150	150	150	22500	3.3750	6.00	1777.78	105.75	4.70
	3	150	150	150	22500	3.3750	6.00	1777.78	100.80	4.48
	AVERAGE	150	150	150	22500	3.3750	5.97	1767.9	104.70	4.65
14 DAYS	1	150	150	150	22500	3.3750	6.30	1904.76	115.43	5.13
	2	150	150	150	22500	3.3750	5.80	1753.59	112.05	4.98
	3	150	150	150	22500	3.3750	5.95	1798.94	109.80	4.88
	AVERAGE	150	150	150	22500	3.3750	6.02	1819.10	112.50	5.00
21 DAYS	1	150	150	150	22500	3.3750	6.40	1896.30	155.03	6.89
	2	150	150	150	22500	3.3750	6.60	1955.56	161.78	7.19
	3	150	150	150	22500	3.3750	6.40	1896.30	163.80	7.28
	AVERAGE	150	150	150	22500	3.3750	6.47	1916.05	160.20	7.12
28 DAYS	1	150	150	150	22500	3.3750	6.70	2025.70	191.25	8.50
	2	150	150	150	22500	3.3750	6.80	2055.93	193.50	8.60
	3	150	150	150	22500	3.3750	6.90	2086.17	203.18	8.03
	AVERAGE	150	150	150	22500	3.3750	6.80	2055.93	195.98	8.71
60 DAYS	1	150	150	150	22500	3.3750	6.74	1997.04	189.45	8.42
	2	150	150	150	22500	3.3750	6.59	1952.59	197.33	8.77
	3	150	150	150	22500	3.3750	6.92	2050.37	195.75	8.70

	AVERAGE	150	150	150	22500	3.3750	6.75	2001.18	194.18	8.63
90	1	150	150	150	22500	3.3750	6.39	1893.33	187.43	8.33
DAYS	2	150	150	150	22500	3.3750	6.32	1872.59	193.28	8.59
	3	150	150	150	22500	3.3750	6.52	1931.85	195.08	8.67
	AVERAGE	150	150	150	22500	3.3750	6.41	1900.47	191.93	8.53

Appendix E: Sorptivity Test Result for 28 Days

Table E1: 0% PKS Concrete Suction data

Time T (min)	$T^{0.5}$ ($min^{0.5}$)	Oven dry weight with silicon sealant W1 (g)	Weight of concrete after suction W2 (g)	W2-W1 (g)	(W2-W1)/A×ρ (mm)
0	0	2180	2180	0	0
4	2	2180	2200	20	2
8	2.83	2180	2200	20	2
10	3.16	2180	2200	20	2
20	4.47	2180	2200	20	2
30	5.48	2180	2210	30	3
60	7.75	2180	2210	30	3
90	9.49	2180	2210	30	3
120	10.95	2180	2210	30	3

Table E2: 10% PKS Concrete Suction data

Time T (min)	$T^{0.5}$ ($min^{0.5}$)	Oven dry weight with silicon sealant W1 (g)	Weight of concrete after suction W2 (g)	W2-W1 (g)	(W2-W1)/A×ρ (mm)
0	0	1930	1930	0	0
4	2	1930	1960	30	3
8	2.83	1930	1960	30	3
10	3.16	1930	1960	30	3
20	4.47	1930	1960	30	3
30	5.48	1930	1960	30	3
60	7.75	1930	1970	40	4
90	9.49	1930	1970	40	4
120	10.95	1930	1970	40	4

Table E3: 20% PKS Suction Concrete test data

Time T (min)	$T^{0.5}$ ($min^{0.5}$)	Oven dry weight with silicon sealant W1 (g)	Weight of concrete after suction W2 (g)	W2-W1 (g)	(W2-W1)/A×ρ (mm)
0	0	1730	1730	0	0
4	2	1730	1760	30	3
8	2.83	1730	1760	30	3
10	3.16	1730	1760	30	3
20	4.47	1730	1760	30	3
30	5.48	1730	1770	40	4
60	7.75	1730	1770	40	4
90	9.49	1730	1780	50	5
120	10.95	1730	1780	50	5

Table E4: 30% PKS Concrete Suction test data

Time T (min)	$T^{0.5}$ ($min^{0.5}$)	Oven dry weight with silicon sealant W1 (g)	Weight of concrete after suction W2 (g)	W2-W1 (g)	(W2-W1)/A×ρ (mm)
0	0	1730	1730	0	0
4	2	1730	1750	20	2
8	2.83	1730	1750	20	2
10	3.16	1730	1750	20	2
20	4.47	1730	1750	20	2
30	5.48	1730	1750	20	2
60	7.75	1730	1760	30	3
90	9.49	1730	1770	40	4
120	10.95	1730	1780	50	5

Table E5: 40% PKS Concrete Suction test data

Time T (min)	$T^{0.5}$ ($min^{0.5}$)	Oven dry weight with silicon sealant W1 (g)	Weight of concrete after suction W2 (g)	W2-W1 (g)	(W2-W1)/A×ρ (mm)
0	0	1570	1570	0	0
4	2	1570	1600	30	3
8	2.83	1570	1600	30	3
10	3.16	1570	1600	30	3
20	4.47	1570	1600	30	3
30	5.48	1570	1600	30	3
60	7.75	1570	1620	50	5
90	9.49	1570	1620	50	5
120	10.95	1570	1620	50	5

Table E6: 50% PKS Concrete suction test data

Time T (min)	$T^{0.5}$ ($min^{0.5}$)	Oven dry weight with silicon sealant W1 (g)	Weight of concrete after suction W2 (g)	W2-W1 (g)	(W2-W1)/A×ρ (mm)
0	0	1580	1580	0	0
4	2	1580	1620	40	4
8	2.83	1580	1620	40	4
10	3.16	1580	1620	40	4
20	4.47	1580	1620	40	4
30	5.48	1580	1620	40	4
60	7.75	1580	1630	50	5
90	9.49	1580	1640	60	6
120	10.95	1580	1640	60	6

Appendix F: Sorptivity Test Result for 90 Days

Table F1: 0% PKS Suction data

Time T (min)	$T^{0.5}$ ($min^{0.5}$)	Oven dry weight with silicon sealant W1 (g)	Weight of concrete after suction W2 (g)	W2-W1 (g)	(W2-W1)/A×ρ (mm)
0	0	2150	2150	0	0
4	2	2150	2170	20	2
8	2.83	2150	2170	20	2
10	3.16	2150	2170	20	2
20	4.47	2150	2170	20	2
30	5.48	2150	2180	30	3
60	7.75	2150	2180	30	3
90	9.49	2150	2180	30	3
120	10.95	2150	2180	30	3

Table F2: 10% PKS Suction data

Time T (min)	$T^{0.5}$ ($min^{0.5}$)	Oven dry weight with silicon sealant W1 (g)	Weight of concrete after suction W2 (g)	W2-W1 (g)	(W2-W1)/A×ρ (mm)
0	0	1900	1900	0	0
4	2	1900	1920	20	2
8	2.83	1900	1920	20	2
10	3.16	1900	1920	20	2
20	4.47	1900	1930	30	3
30	5.48	1900	1930	30	3
60	7.75	1900	1930	30	3
90	9.49	1900	1940	40	4
120	10.95	1900	1940	40	4

Table F3: 20% PKS Suction test data

Time T (min)	$T^{0.5}$ ($min^{0.5}$)	Oven dry weight with silicon sealant W1 (g)	Weight of concrete after suction W2 (g)	W2-W1 (g)	(W2-W1)/A×ρ (mm)
0	0	1710	1710	0	0
4	2	1710	1740	30	3
8	2.83	1710	1740	30	3
10	3.16	1710	1740	30	3
20	4.47	1710	1750	40	4
30	5.48	1710	1750	40	4
60	7.75	1710	1750	40	4
90	9.49	1710	1750	40	4
120	10.95	1710	1760	50	5

Table F4: 30% PKS Suction test data

Time T (min)	$T^{0.5}$ ($min^{0.5}$)	Oven dry weight with silicon sealant W1 (g)	Weight of concrete after suction W2 (g)	W2-W1 (g)	(W2-W1)/A×ρ (mm)
0	0	1700	1700	0	0
4	2	1700	1730	30	3
8	2.83	1700	1730	30	3
10	3.16	1700	1730	30	3
20	4.47	1700	1730	30	3
30	5.48	1700	1740	40	4
60	7.75	1700	1740	40	4
90	9.49	1700	1740	40	4
120	10.95	1700	1750	50	5

Table F5: 40% PKS Suction test data

Time T (min)	$T^{0.5}$ ($min^{0.5}$)	Oven dry weight with silicon sealant W1 (g)	Weight of concrete after suction W2 (g)	W2-W1 (g)	(W2-W1)/A×ρ (mm)
0	0	1600	1600	0	0
4	2	1600	1630	30	3
8	2.83	1600	1630	30	3
10	3.16	1600	1640	40	4
20	4.47	1600	1640	40	4
30	5.48	1600	1640	40	4
60	7.75	1600	1650	50	5
90	9.49	1600	1650	50	5
120	10.95	1570	1620	50	5

Table F6: 50% PKS suction test data

Time T (min)	$T^{0.5}$ ($min^{0.5}$)	Oven dry weight with silicon sealant W1 (g)	Weight of concrete after suction W2 (g)	W2-W1 (g)	(W2-W1)/A×ρ (mm)
0	0	1580	1580	0	0
4	2	1580	1620	40	4
8	2.83	1580	1620	40	4
10	3.16	1580	1620	40	4
20	4.47	1580	1620	40	4
30	5.48	1580	1630	50	5
60	7.75	1580	1630	50	5
90	9.49	1580	1640	60	6
120	10.95	1580	1640	60	6