SUITABILITY OF PALM KERNEL SHELLS AS COARSE AGGREGATE FOR STRUCTURAL USE

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ABSTRACT

This study looks into the Suitability of palm kernel shells as coarse aggregate for structural use. The tests conducted were sieve analysis, water absorption test, bulk density, specific gravity, slump test and compressive strength. A design mix ratio of 1:3:5 and water-cement ratio of 0.65 were adopted for both PKSC and NWC (Control). Cubes (150mm×150mm×150mm) were cast and cured for periods of 3, 7, 14, 21, 28 and56 days and their densities and compressive strengths were determined. The 28 days average compressive strength of PKSC was found to be 19.80 N/mm^2, while that of control was found to be 23.28 N/mm^2. The Specific gravities of crushed stone, and Palm Kernel Shell were found to be 2.62 and 1.32 while their bulk densities were 1755 and 632 kg/m^3 respectively. Water absorption capacity of palm kernel shell was found to be 21.50%, while that of crushed stone was found to be 0.23% for 24hrs. In conclusion, Palm Kernel Shells Aggregate (PKSA) posse properties that is suitable for Light Weight Aggregate (LWA) and the compressive strength of PKSC which is19.80 N/mm^2 is above the minimum recommended by codes for structural Light Weight Concrete (LWC). Hence, PKSC can be used for structural members like beam, slab, and even column. It reduces the cost of construction; pollution associated with waste disposal and enhances infrastructural development.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Palm Kernel Shell (PKS) is a stiff, non-toxic, readily available material, corrosion resistant, and a light weight organic solid waste materials gotten from the processing of red oil from palm nuts. PKS can also be defined as rigid, carbonaceous and organic waste materials of the processing of palm oil nuts (Alengaram *et al*, 2010). In the same vain, Palm Kernel Shell Concrete (PKSC) is a concrete in which PKS serves as coarse aggregate replacing crushed granite or normal aggregate.

Concrete in the other hand, can be described as material which is formed from a calculated mixture of cement, aggregates (fine and coarse) and water, which when set or hardened form the shape of the container or form work that later results into a solid mass when cured at the suitable weather condition (Alawode *et al,* 2011). It is also defined in student Encarta as a control mixture of cement, aggregate and water in certain proportions which solidify to form a firm or rigid stony consistency over length of time. American Concrete Institute defines concrete as an engineering material formed from a mixture of Portland cement, water, fine and coarse aggregate and some amount of air.

Concrete is also defined as a mixture of aggregates and a paste consisting of a Portland cement and water. The aggregate refer to sand and gravels or crushed stones. The suitability of a material is regarded as its ability to perform a specified or required function under specified conditions without failure for a stated period of time.

Some of the advantages of PKSC over Normal Weight Concrete (NWC) are savings on reinforcement, formwork, scaffolding, foundation costs as well as the savings derived from the reduced cost of transport and erection.(Shafigh *et al,* 2010)

Low permeability of concrete improve resistance to the penetration of water, Chloride ions, Alkali ions, Sulphate ions and other harmful substances which can cause concrete attack. Concrete is said to be suitable or durable when it can serve its purpose without failure or deterioration for a very long period of time. Concrete is brittle and low in tension but has compressive strength which is higher than the tensile strength (Mosley and Bunger, 2000).

Basically building industry depends largely on common materials such as cement, coarse and fine aggregate for concrete production. The high and increasing cost of these materials has largely affected the development of shelter and other infrastructural facilities in developing countries. There is need for engineering industry to consider the use of waste and readily available materials to bring down to the barest minimum the cost of construction for sustainable development.

Most coarse aggregates from quarries are very expensive and the operations that lead to the production of those aggregates pose dangers to human being and its environment. In order to alleviate the incessant increasing demand for low cost and eco-friendly construction materials, while strengthening economic growth and competitiveness, the use of PKSC becomes eminent in construction industries.

PKS can be an ideal construction material for Light Weight Concrete (LWC) because of its excellent properties such as; non-toxic, readily available, strong, stiff, light weight, and corrosion resistant (Atteh, 2012).

In Nigeria, it was estimated that more than 1million tons of PKS waste is generated yearly and just a fraction is been consumed for fuel (for steam boilers at palm oil mills) and other uses (Shafigh *et al,* 2010). Some of the major palm oil producing states in Nigeria includes, Ogun, Osun, Ondo, Oyo, Edo, Cross River, Anambra, Enugu, Imo, Abia, Ekiti, Akwa-Ibom, Delta and Rivers (Oluremi et al., 1990). There are large amount of PKS wastes in open places in those states in Nigeria constituting nuisance and negative impact on the environment. Some accumulate water for breeding of mosquitoes, while others also block water ways by clogging the local drains.

1.2 Problem Statement

The earlier researchers like Okafor (1988) and Abdullah (1984) have only proved that the PKS are good coarse aggregate for production of LWC used for masonry and mass concrete.

The intention of this research work is to investigate if PKS is a good coarse aggregate for structural elements such as slab, beam and column.

1.3 Aim of the study

The aim of this research work is to investigate the suitability of PKS as coarse Aggregate for Structural use.

1.3.1 Objectives of the study

In order to achieve the aim above, the objectives of this research work are to determine;

i. The physical properties of aggregates.

ii. The mechanical properties of PKSC.

1.4 Justification of study

The high demand for normal concrete in the building industry using normal granite coarse aggregate has largely reduced the availability of natural stone deposit which led to the distortion of the environment resulting to imbalance in the ecosystem (Short and Kinnibursh, 1978). There is also need to do more research in order to find alternative material to granite aggregate to help sustain the natural stone deposit

The use of PKS will reduce rapidly the cost of construction and create means of PKS waste disposal. Through the use of PKS as Engineering material, the economic potential of peasant farmers which specialized in Palm trees will be improved.

1.5 Scope of the Research

The scope of this research work include laboratory test on PKS, crushed stone and sharp sand in order to determine their physical properties such as water absorption test, sieve analysis, bulk density, dry density and specific gravity test. Mechanical test is also carried out on the PKSC and NWC. The results from both the physical and mechanical properties of PKS are analyzed in order to determine the suitability of Palm Kernel Shell Aggregate (PKSA) for structural use.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 General Overview

The growing need for sustainable development has motivated researchers to focus their attention on the use of waste materials as potential construction material. There are a number of studies related to PKS as Light Weight Aggregate (LWA) concrete especially for lightweight structures (Shfigh *et al,* 2012) Aggregates are normally refers to as naturally occurring gravel or crushed rock and sand, also synthetic materials are being used, for example, to produce concrete of lower density.

High and continuous rise in the cost of construction is one of the main problems the construction industries are battling. Great numbers of developmental construction works are wholly dependent on the cost of production which is the function of the cost of materials (Anthony 2000). In this regards, (Shetty, 2005) reported that the total cost of concrete elements depends solely on the amount of materials and labour. Coarse aggregates take up to 70-80% of total volume of a concrete (Falade *et al,* 2010), this means percentage of aggregate in concrete is of reasonable amount. The use of agricultural and industrial by-products has now become major important alternative to the use of granite which generates noise pollution in the process of production.

PKS is agro-based waste materials generated from the production of red oil; the disposal of which is an environmental problem of concern. The scarcity and high cost of aggregate is a great set back in terms of time and cost of construction, since aggregate forms the largest percentage of the content of the concrete.

Abdullah (1984) was among the first researchers on PKS as LWA. He submitted that it is possible to replace completely the NWA with PKS. The use of agricultural wastes as aggregate in concrete has a lot of engineering potential and advantage especially in low-cost non-load bearing light weight concrete, where compressive strength is not important and also reduces the cost of construction greatly. .

Okafor (1988) worked on the mechanical properties of PKSC and proved that similar to NWC; water to cement ratio (w/c) is a major factor affecting the mechanical properties of PKSC.

Also, from (Alengaram *et al,* 2010) work on the investigation of physical and mechanical properties of various sizes of PKS as LWA and their influences on the properties of Palm Kernel Shell Concrete (PKSC) submitted that the 28days compressive strength is in the ranges of 21 to 26MPa. In his work he also shows that PKS consists of about 65 to 70% of medium size particles ranges from 5 to 10mm.

Acheampong *et al*, (2013) conducted a comparative study of the physical properties of PKSC and NWC with various cement types reported that the density of the PKSC was about 22 percent lower than that of the NWC for all the cement types. But here the same cement type will be used to determine the suitability of the aggregate.

A research carried out by Neville (2000) concluded that the use of PKS as an Engineering construction material could have other advantages in concrete other than serving as light weight concrete. He further submitted that some of the usefulness is the reduction in the density of the concrete and the form work is also subjected to lesser pressure than it will be if NWC is used.

Various methods have been adopted by various researchers to bring down the total cost of concrete constituent and hence total cost of construction by investigating and utilizing the potential of materials which is classified as agricultural or industrial waste. In the work of (Ndoke, 2006), an assessment was carried out into the performance PKS as a partial replacement for coarse aggregate in asphalt concrete production and submitted that PKS could be used up to 45% in the production of asphalt concrete since PKS do excellently when partially replaced in concrete production.

In the work of Olutoge (1995) on the properties of PKS, the bulk density was discovered to be 740kg/m^3. From his finding, it was concluded that PKSA possessed properties that are similar to that of Light Weight Concrete Aggregates.

Olanipekun (2006) examined the properties of coconut shells and PKS and discovered a cost reduction of 30% for concrete from coconut shell and 42% for concrete PKS when compared with normal or conventional concrete.

Other previous works done by other researchers have shown that the air-dry density of PKSC was in the range of 1725 to 1900kg/m^3 (Abdulla, (1984); Okafor, (1988); Mannan and Ganapathy, (2002); Olanipekun, (2006);. Compressive strength was also found between 5 and 25Mpa. Though the compressive strength of PKSC fulfills the requirement for light weight concrete, higher strength of about 30Mpa is preferred for medium strength structural element.

In order to enhance some of the properties and control the setting time of concrete, admixtures can be added to the mix. The chemical reactions that occur when various constituent materials are mixed can vary based on the properties of the constituent materials Alengaram *et al,* (2008). The materials can differ in their chemical content and performance characteristics, based on where they were mined or quarried, and according to the process of manufacturing and conditions in the manufacturing plant.

Many Researches have been carried out by several researchers in the past focusing on how to improve the flexural and strength properties of PKSC through or with the addition of mineral admixture like fly ash and silica fume among others. Some of the studies done in this area include the works of Neville (1995), and Teo *et al,* 2008. Neville (1995) had reported that silica fume (SF) has the capacity to restrain reactions at the surface of the aggregate to strengthen the strong bond between the aggregate and the cement paste. This inclusion of silica fume strengthens the area of weakness being the area between the aggregate and the cement paste interface. The weaker joint between aggregate-matrix enhances the lower tensile strength in PKSC.

In NWC, the non-smooth surface of aggregate increase the bond and hence increase tensile strength. Silica Fume (SF) is always employed in the production of PKSC of grade 30 and above mainly to improve the bond between the smooth convex surfaces of Palm Kernel Shell and cement matrix.

2.2 Light Weight Aggregate

Light Weight Aggregate concrete is not a recent idea in concrete technology; it has been utilized for a very long time. The fact that some of the old structures made from Light Weight Aggregate still remained in good shape proves the durability of concrete made from Light weight Aggregate (Chandra and Berntsson, 2002).

There are two groups of Light Weight Aggregate: The naturally occurring aggregates and the manufactured aggregates. The major natural Light Weight aggregates are diatomite, pumice, scoria, volcanic cinders and tuff. Manufactured aggregates can also be divided into two major groups. The first one is naturally occurring materials that require further processing such as expanded clay, shale, slate, perlite and vermiculite while the second is waste or industrial by-products such as sintered pulverized-fuel ash (fly ash).

PKS is another alternative Light Weight aggregate found in tropical regions and nations that have a palm oil industry. The past researches on using Palm Kernel Shell as Light Weight Aggregate produced compressive strength in the range of 15-25 MPa (Abdullah, 1984; Okafor, 1988; Basri *et al.,* 1999). The mechanical properties of PKS concrete depend on factors such as cement, water, sand and aggregate contents and density, one of the best ways to increase the bond is to identify the impart of sand content in LWC

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.2 Selection and Preparation of Materials

3.1.1 Palm kernel shell: Palm Kernel Shells which serve as coarse aggregate for this research work was sourced from a local red oil producing community of oju, in oju local government area of Benue State Nigeria. PKS was prepared by soaking the sample for 24hrs in the detergent to remove all the oily dirty from the sample. After that, the shells were washed and sundried in the open air. Pre-treatment was also done to clear impurity such as oil coating and other dirty from the shells. It was ensured that the sample was well-rinsed before sundry and after that the sample was kept in airtight water proof sacks.

3.1.2 Cement: Ordinary Portland cement (Dangote) with specific gravity 3.0 was utilized. The cement was conformed to the specification of BS EN 197-1:2011. It was ensured that the containers were airtight and very dried, free from every liquid. The cement used for this research was sourced from Dangote mini-cement deport minna Niger state of Nigeria.

3.1.3 Water: A potable water supply from FUTMinna Civil Engineering Laboratory was utilized for the experiment. The water is drinkable and conformed to BS 3148 (1980).

3.1.4 Fine and coarse aggregate: The aggregates for this research work were naturally occurring clean river sharp sand (fine aggregate) and crushed granite (Coarse aggregate). The fine aggregate were sourced from Chanchagan River in Minna Niger state, while the coarse aggregate were sourced from a quarry site in Abuja. The sharp sand and coarse aggregate were prepared according to the specification of BS 882 (1992).

3.2 Research Procedure

3.2.1 Concrete mix design (BS method)

The method adopted for this research work was in accordance to the method published by the Department of Environment, (DOE) United Kingdom (1998), with reference to IS 456:2000. From the design the quantities of different concrete constituents, mix ratio and w/c ratio were arrived at.

Table 3.1: Quantity of constituent materials for batching

Materials	Cement	Water	Fine Aggregate	Coarse Aggregate
Quantity (kg)	104.88	68.18	293.27	487.11

3.2.2 Specific gravity test

The specific gravity of the materials was carried out according to the specification of ASTM C 127- 07, (2007). The test was carried out on both the fine and coarse aggregate to determine their strength and quality as shown in plate I.

Plate I: Specific gravity test

3.2.3 Bulk density test

The bulk density was carried out on the materials in accordance to BS 812-2 1995. The test also conform to the procedures described in ASTM C 29/C29M (2003). Below are the plate II, II and III showing the apparatus and procedures for measuring bulk density.

Plate II: Measuring (PKSA) for bulk density test

Plate III: Compressed bulk density test on fine aggregate

Plate IV: Compressed bulk density test on (PKSA)

3.2.4 Water absorption test

Water Absorption test on aggregates was carried out in accordance with BS 1881 (1983)-Part 122.

3.2.4 Sieve analysis

Sieve analysis was carried out on both the fine and coarse aggregate to determine their gradation and particle distribution of aggregate size. It was ensured that the experimental procedures conform to the requirements of ASTM 136 (2003).

3.2.5 Slump test

Fresh concrete is said to be workable only when it can easily be placed, compacted, transported and casted without segregation. In this research, the slump test procedures were carried out in accordance to BS 1881: Part 102: (1983). The Slump test was conducted on fresh concrete for both Palm Kernel Shell and crushed granite which serve as control to know the workability of concrete.

3.2.7 Compressive strength test

Compressive strength test was carried out on the Palm Kernel Shell Concrete (PKSC) and Normal Weight Concrete (NWC) the control, in accordance to BS EN 12390-2:2009 to determine their ultimate strength at 3, 7, 14, 21, 28 and 56days for analysis. All specimens were totally immersed in curing tank for 3, 7, 14, 21, 28 and 56days, after this the cubes were brought out of the curing tank and allowed to rest for two hours before crushing to determine their strength properties. The density of each specimen was also determined before crushing. Five replicates were made for specimens at each curing age for PKS and the control.

A total of 60 specimen cubes were crushed for the compressive strength test including the control. The average values of the maximum loads, at which each group of the five specimens failed, were recorded as the compressive strength. The compressive strength test was determined with reference to the guidelines outlined by the BS and ASTM.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Physical Properties of Aggregates

4.1.1 Particle Size Distribution of Aggregates

Fineness Modulus (FM), Coefficient of Curvature (C_C) and Coefficient Uniformity (C_U) values are the three major tools to be used for the grading of aggregate here. According to BS EN 12620:1, the values for Coefficient of curvature (*Cc*) should lie between one and three for well graded gravel and sand whereas the Uniformity coefficient (*Cu*) should be more than four for well graded gravel and more than six for well graded sand.

As presented in table 4.4, it can be observed that the values of Cc =1.28, 2.10 and 1.6 for sand, PKS and crushed granite respectively satisfy the condition of well graded aggregate of being between one and three according to BS EN 933-1:1997.

Also the range for fineness modulus according to specifications from ASTM C 33 (2003) is 2.3 to 3.1 and from the results presented in Table 4.4 the fineness modulus of the sand used in this research was found to be 2.66 which fall within the range of 2.3 to 3.1. This value also satisfied the requirement of BS EN 12620-1, 2007 for well graded sand.

Similarly, from the same results of Table 4.4 the Coefficient of uniformities (*Cu*) of the sand, gravel and Palm Kernel Shell is 6.1, 1.4 and 1.2, respectively satisfied the condition for a well graded aggregate. Hence, the sand, gravel and Palm Kernel Shell used for the study are well graded and suitable for production of concrete. Table 4.1, 4.2 and 4.3 show the particle size distribution of aggregates while Figure 4.1, 4.2 and 4.3 show their Distribution curves.

Table 4.1: Particle size distribution for PKS

Sieve size (mm)	Mass retained (g)	%Mass retained	%Cumulative mass retained	%mass passing
26.5	0	0	0	100
19.0	0	0	0	100
13.0	29	2.9	2.9	97.1
6.3	864	86.4	89.3	9.9
5.6	41	4.1	93.4	6.6
4.75	29	2.9	96.3	3.7
2.36	19	1.9	98.2	1.8
Pan	18	1.8	100	

Table 4.2 : Particle size distribution for Coarse Aggregate

Sieve size (mm)	Mass retained (g)	%Mass retained	%Cumulative mass retained	%mass passing
26.5	175	17.5	17.5	82.5
19.0	496	49.6	67.1	32.9
13.0	257	25.7	92.8	7.2
6.3	64	6.4	99.2	0.8
5.6	0	0	99.2	0.8
4.75	0	0	99.2	0.8
2.36	0	0	99.2	0.8
Pan	8	0.8	100	

Table 4.3: Particle size distribution for fine aggregate

Sieve size (mm)	Mass retained (g)	%Mass retained	%Cumulative mass retained	%mass passing
4.750	16	1.6	1.6	98.4
2.360	50	5.0	6.6	93.4
1.180	151	15.1	21.7	78.3
0.600	403	40.3	62	38.0
0.420	136	13.6	75.6	24.4
0.300	89	8.9	84.5	15.5
0.210	42	4.2	88.7	11.3
0.150	35	3.5	92.2	7.8
0.075	11	1.1	93.3	6.7
Pan	67	6.7	100	

The particle size distribution curves for the aggregates used for the research are shown in Figure 4.1, 4.2 and 4.3.

4.1.2 Specific gravity, bulk density and water absorption

According to ASTM C 127 (2007), specific gravity is defined as the ratio of the density of a material to that of distilled water at a stated temperature.

Specific gravity is used in the determination of voids in aggregates. The results presented in Table 4.4 show that the specific gravity obtained for the Palm Kernel Shell is 1.32.

The high porosity of Palm Kernel Shell may have contributed immensely to the low specific gravity value obtained compared with the specific gravity obtained for the normal aggregate of 2.62, which is considered adequate for normal weight aggregate. The difference in the specific gravities imply that for every given mix design, the Palm Kernel Shell concrete would contain a much higher volume of coarse aggregate than the normal weight concrete, if batching is done by weight.

From Table 4.4 the bulk density of sand is 1737 kg/m^3, that of PKS is 632kg/m^3 and that of crushed granite is 1755 kg/m^3. According to ASTM C330 (1999), these values of the bulk densities for sand and gravel lie within the range of bulk densities for normal weight aggregate which is 1450 – 1600 kg/ m^3. The Palm Kernel Shell has a bulk density of 632kg/m^3 and the value satisfied the requirement for lightweight aggregate.

Also as presented in Table 4.4, the average moisture content of samples of Palm Kernel Shells tested was 11%. This value is considered high, suggesting high water absorption rate.

Table 4.4: Physical Properties of Aggregates

S/n	Property	Cement	Sand	Palm Kernel Shell	Crushed Stone
1.	Bulk Density(kg/m^3 Compressed	-	1737	632	1755
2.	Bulk Density(kg/m^3) Uncompressed	-	1610	566	1725
3.	Specific gravity	3.0	2.72	1.32	2.62
4.	Water absorption (%) (1hr)		<1	11	0.23
5.	Water absorption (%) (24hrs)		<1	21.5	0.23
6.	Fineness modulus (FM)		2.66	3.80	2.74
7.	Coefficient of Uniformity (Cu)		6.10	1.20	1.4
8.	Coefficient of curvature (Cc)		1.28	2.10	1.6

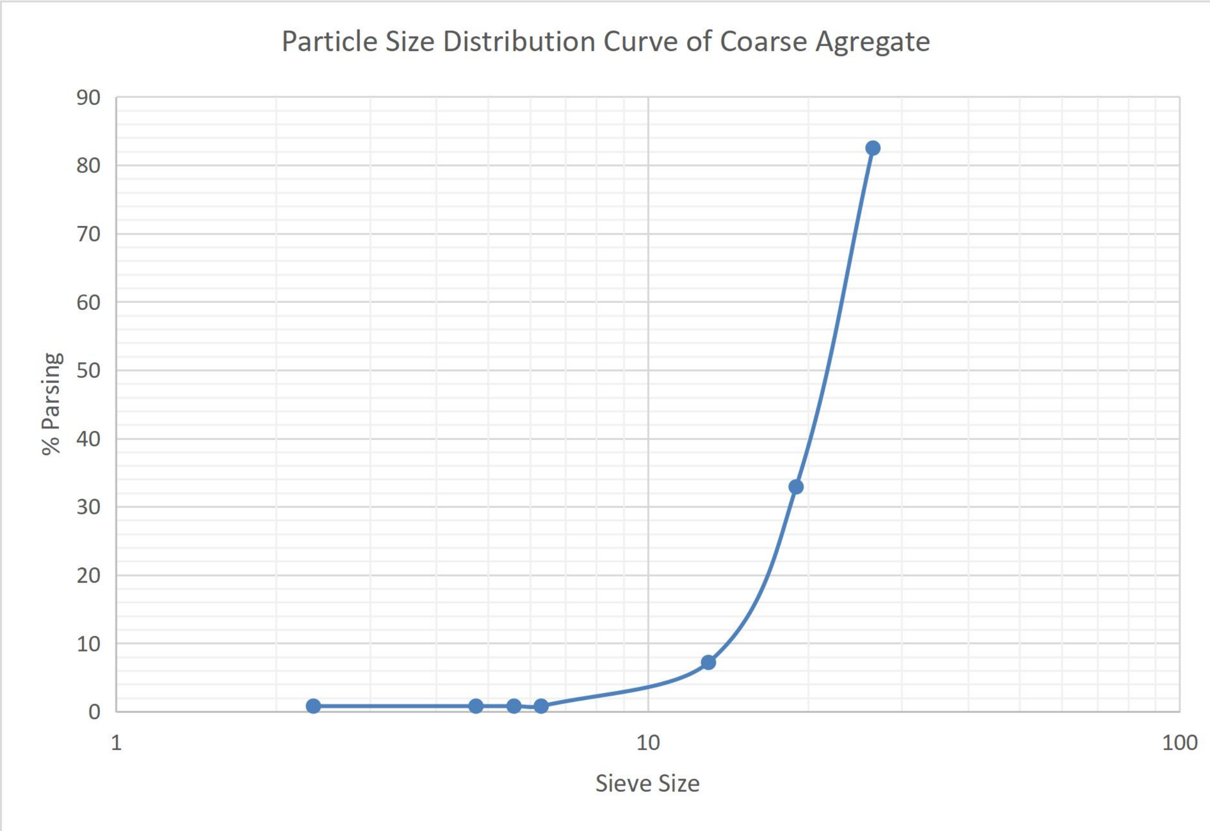

Figure 4.1: Particle size distribution curve of coarse aggregate

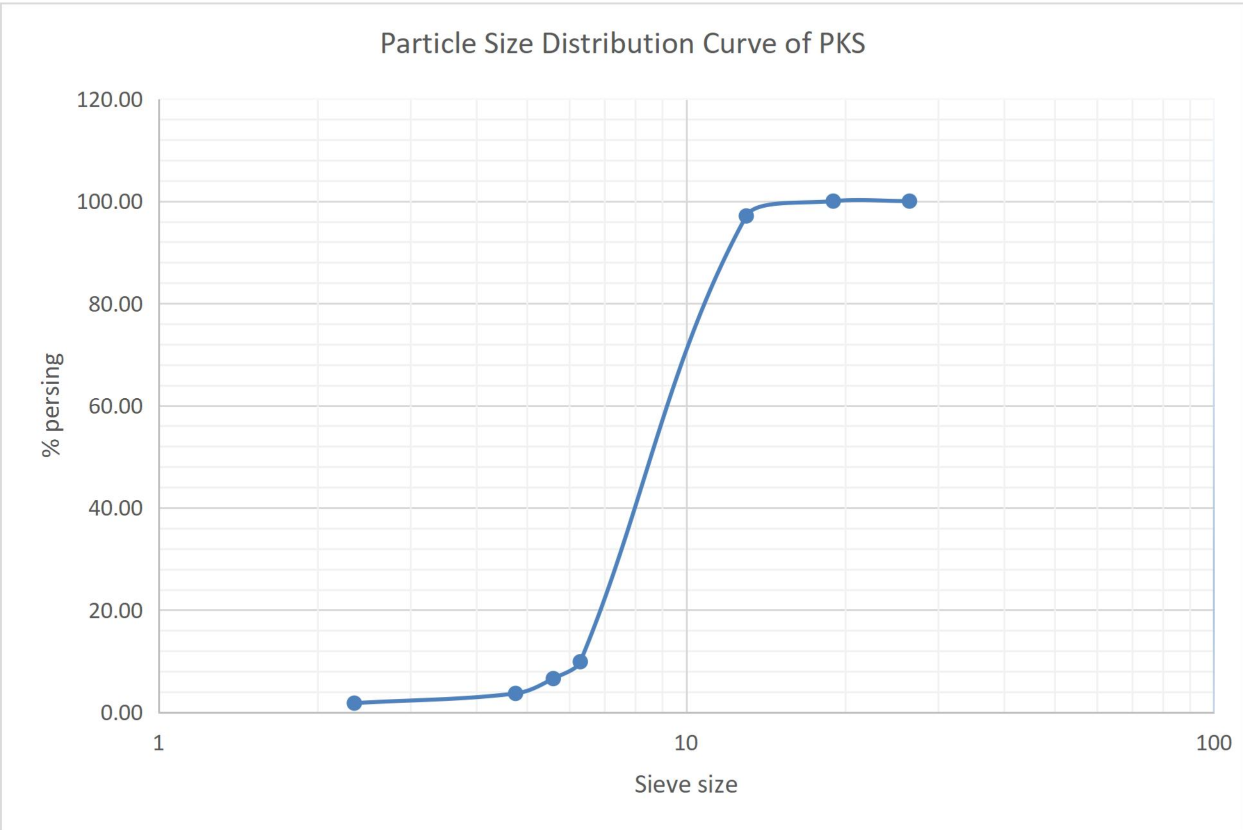

Figure 4.2: Particle size distribution curve of PKS

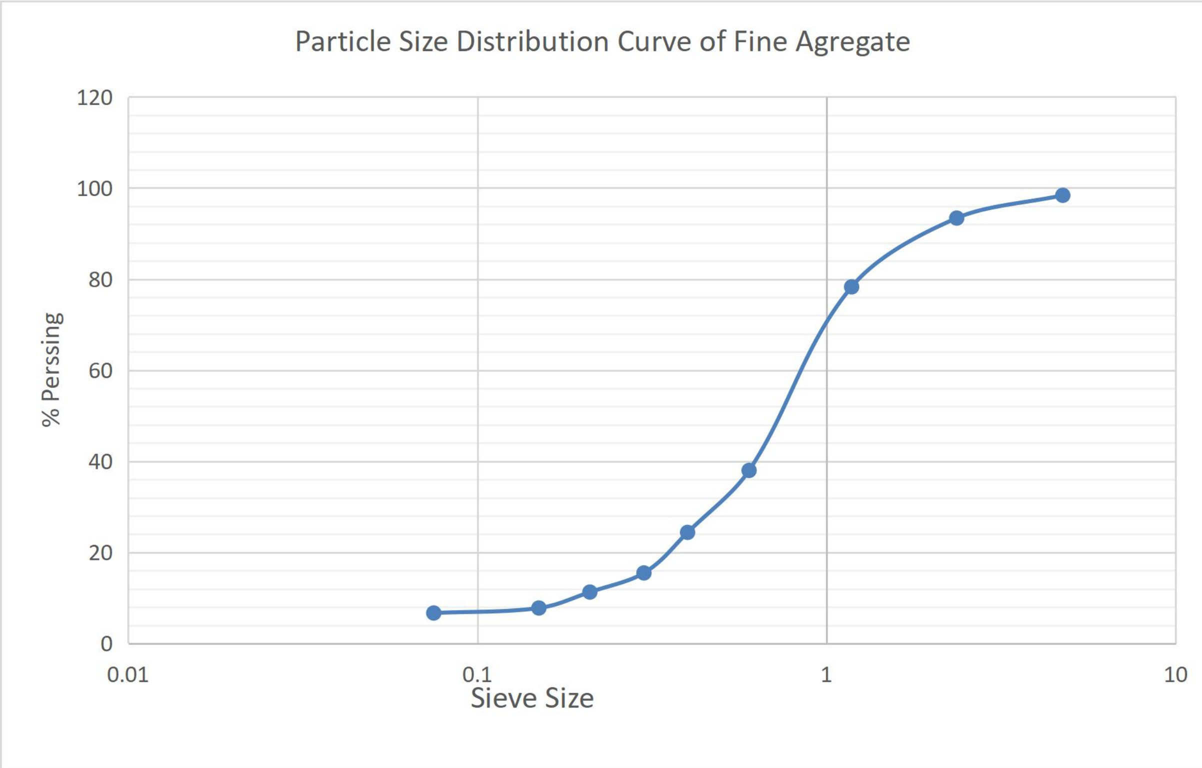

Figure 4.3: Particle size distribution curve of fine aggregate

4.1.3 Density of concrete

The results of the density tests are presented in Table 4.5, Table 4.6, and Table 4.7. Table 4.8 presented the average density of palm kernel shell concrete which is calculated from the previous tables. From table 4.8, it can be observed that the mean density of palm kernel shell concrete at 28 is 1794 Kg//m^3. The density of the palm kernel shell concrete is less by over 20% with reference to normal weight concrete. The density of palm kernel shell concrete depends on various factors such as, the specific gravity of palm kernel shell, water cement (w/c) ratio, sand, palm kernel shell contents and water absorption of palm kernel shell (Alengaram *et al.,* 2013). Consequently, the density of palm kernel shell concrete produced in this research lies within the range of densities of light weight concrete, hence it can be deduced that the concrete is a lightweight concrete.

The higher specific gravity of granite aggregate in the normal weight concrete produced higher concrete density. On the other hand, the lower specific gravity of palm kernel shell contributed to lower density of the palm kernel shell concrete.

The unit weight of Palm kernel shell, being a lighter material, is lower than the unit weight of natural aggregates mainly from rock fragments. The range for density for structural lightweight concrete is 1440 to 1850 kg/m^3 (ACI Committee 213R-87, 2003). According to Clarke (1993) the density of palm kernel shell concrete usually falls in the range of 1600-1900 kg/m^3 due to lower density of palm kernel shell. He also reported that for structural lightweight concrete, the density is between 1200 and 2000 kg/m^3. Neville (1995) observed the density of structural lightweight concrete to be between 350 and 1850 kg/ m^3.

The density of 1794 kg/m^3 recorded at curing age of 28days fall within the range for structural lightweight concrete and suggests that palm kernel shell can be used as structural lightweight concrete (ASTM C 330. 2004).

Table 4.5: 3Days and 7days density of PKSC

S/n	Weight(kg)		Density(kg/m^3)		Mean Density(kg/m^3)		Standard deviation	
	3days	7days	3days	7days	3days	7days	3days	7days
1.	6.15	5.79	1822.22	1715.56	1679.58	1691.56	5.14	3.58
2.	6.17	5.73	1828.15	1697.78				
3.	5.82	5.67	1724.44	1680.00				
4.	5.79	5.61	1716.06	1662.22				
5.	5.94	5.76	1760.00	1706.67				
6.	6.16	5.68	1825.19	1682.96				
7.	5.83	5.60	1727.41	1659.26				
8.	5.78	5.77	1712.59	1709.63				
9.	5.95	5.78	1762.96	1712.59				
10.	6.14	5.74	1819.26	1700.74				
11.	6.16	5.78	1825.19	1712.59				
12.	5.93	5.63	1757.04	1668.15				
13.	5.80	5.67	1718.52	1680.00				
14.	5.85	5.75	1733.33	1703.70				
15.	6.15	5.81	1822.22	1721.48				
16.	5.96	5.77	1765.93	1709.63				
17.	5.78	5.71	1712.59	1691.85				
18.	5.84	5.65	1730.37	1674.07				
19.	6.17	5.54	1828.15	1641.48				
20	6.15	5.74	1822.22	1700.74				

Table 4.6: 14Days and 21days density of PKSC

S/n	Weight(kg)		Density(kg/m^3)		Mean Density(kg/m^3		Standard deviation	
	14days	21days	14days	21days	14days	21days	14days	21days
1.	5.75	6.00	1703.70	1777.78	1674.81	1754.07	97.20	70.50
2.	5.63	6.47	1668.15	1917.04				
3.	5.60	6.15	1659.26	1822.22				
4.	5.56	5.75	1647.41	1703.70				
5.	5.72	6.01	1694.81	1780.74				
6.	5.62	5.77	1665.19	1709.63				
7.	5.58	6.17	1653.33	1828.15				
8.	5.74	6.49	1700.74	1922.96				
9.	5.65	6.02	1674.07	1783.70				
10.	5.77	6.03	1709.63	1786.67				
11.	5.73	5.58	1697.78	1653.33				
12.	5.61	6.45	1662.22	1911.11				
13.	5.58	6.13	1653.33	1816.30				
14.	5.54	5.73	1641.48	1697.78				
15.	5.70	5.59	1688.89	1656.30				
16.	5.76	6.01	1706.67	1780.74				
17.	5.62	6.46	1.665.19	1914.07				
18.	5.61	6.16	1662.22	1825.19				
19.	5.55	5.76	1644.44	1706.67				
20.	5.73	6.02	1697.78	1783.70				

Table 4.7: 28Days and 56days density of PKSC

S/n	Weight(kg)		Density(kg/m^3)		Mean Density(kg/m^3		Standard deviation	
	28days	56days	28days	56days	28days	56days	28days	56days
1.	6.01	5.72	1780.74	1694.81	1794.10	1734.50	63.41	78.49
2.	5.99	5.69	1774.81	1685.93				
3.	5.70	6.60	1688.89	1955.56				
4.	5.96	5.58	1765.93	1653.33				
5.	5.94	5.68	1760.00	1682.96				
6.	6.00	5.74	1777.78	1700.74				
7.	6.00	5.70	1777.78	1688.89				
8.	5.60	5.65	1659.30	1970.37				
9.	5.94	6.55	1760.00	1940.74				
10.	5.92	6.58	1754.07	1949.63				
11.	6.02	5.66	1783.70	1677.04				
12	5.98	6.54	1771.85	1937.78				
13	5.78	6.68	1712.59	1979.26				
14	5.98	5.71	1773.43	1692.86				
15.	5.96	5.72	1765.93	1694.81				
16.	5.96	5.67	1765.93	1680.00				
17.	5.98	6.59	1771.85	1952.59				
18.	5.80	6.56	1718.92	1943.70				
19.	5.90	6.70	1748.15	1985.19				
20.	6.00	5.72	1777.78	1694.81				

Table 4.8: Mean density of PKSC cubes

S/n	Curing Age (days)	Mean Density of PKSC Cubes (kg/m^3)
1.	3	1679.58
2.	7	1691.56
3.	14	1674.81
4.	21	1754.07
5.	28	1794.10
6.	56	1734.52

4.1.4 Compressive Strength of Concrete

The results of the compressive strength test of PKSC at 3, 7, 14, 21, 28 and 56days are presented in Table 4.9, 4.10 and 4.11 while the mean compressive strength is presented in Table 4.12. As expected, the compressive strength of the concrete increases with curing age with the 3-day concrete cube attaining the lowest compressive strength while the 56-day concrete had the highest compressive strength. It can also be observed that, compressive strength of concrete increases rapidly at first within the first few days and the increase in compressive strength later becomes stead and gradual.

In BS 8110-1 (1997), it is recommended that the minimum compressive strength for reinforced concrete made with LWA to be equal to or greater than 15N/mm^2 while Shetty (2005) defines structural LWC as a concrete having 28-day compressive strength greater than 17N/mm^2. From Table 4.9, it can be observed that the 28-day compressive strength of PKSC is 19.80N/mm^2 which is higher than the minimum strength of 17.00N/mm^2 stipulated by (ASTM C330, 1999) for LWC

Table 4.9: 3Days and 7days concrete compressive strength of PKSC

S/n	Wt of cube(kg)		Crushing load(N)		Comp. Strength (N/mm^2)		Mean Comp. Strength (N/mm^2)	
	3days	7days	3days	7days	3days	7days	3days	7days
1.	6.15	5.79	200,000	350,000	8.90	15.60	14.10	11.50
2.	6.17	5.73	300,000	400,000	13.30	17.80		
3.	5.82	5.67	250,000	300,000	11.10	13.30		
4.	5.79	5.61	250,000	270,000	11.10	12.00		
5.	5.94	5.76	300,000	260,000	13.30	11.60		
6.	6.16	5.80	260,000	280,000	11.60	12.40		
7.	6.18	5.68	240,000	250,000	10.70	11.10		
8.	5.81	5.68	290,000	240,000	12.90	10.70		
9.	5.81	5.62	220,000	380,000	9.80	16.70		
10.	5.78	5.75	280,000	330,000	12.40	14.70		
11.	5.94	5.77	300,000	280,000	13.30	12.40		
12.	5.83	5.60	310,000	290,000	13.80	12.90		
13.	5.80	5.66	260,000	320,000	11.60	14.20		
14.	5.95	5.60	270,000	420,000	12.00	18.70		
15.	6.14	5.74	280,000	370,000	12.40	16.40		
16.	6.16	5.68	200,000	340,000	8.90	15.10		
17.	5.93	5.62	320,000	410,000	14.20	18.20		
18.	5.78	5.75	240,000	280,000	10.70	12.40		
19.	5.80	5.78	200,000	280,000	8.90	12.40		
20.	6.16	5.74	260,000	260,000	11.60	11.60		

Table 4.10 7Days and 14days concrete compressive strength of PKSC

S/n	Wt of cube(kg)		Crushing load(N)		Comp. Strength (N/mm^2)		Mean Comp. Strength (N/mm^2)	
	14days	21days	14days	21days	14days	21days	14days	21days
1.	5.75	6.00	370,000	350,000	16.40	15.60	17.70	16.21
2.	5.63	6.47	420,000	470,000	18.70	20.90		
3.	5.60	6.15	330,000	480,000	14.70	21.30		
4.	5.56	5.75	300,000	340,000	13.30	15.10		
5.	5.72	6.01	290,000	350,000	12.90	15.60		
6.	5.76	6.10	360,000	360,000	16.00	16.00		
7.	5.64	6.45	410,000	480,000	18.20	21.30		
8.	5.61	6.05	320,000	490,000	14.20	21.80		
9.	5.57	5.70	290,000	350,000	12.90	15.60		
10.	5.73	6.00	280,000	360,000	12.40	16.00		
11.	5.71	5.95	300,000	340,000	13.30	15.10		
12.	5.55	6.50	310,000	460,000	13.80	20.40		
13.	5.59	6.20	340,000	470,000	15.10	20.90		
14.	5.62	5.55	430,000	330,000	19.10	14.70		
15.	5.74	6.02	380,000	340,000	16.90	15.10		
16.	5.62	6.01	390,000	370,000	17.30	16.40		
17.	5.54	6.47	400,000	450,000	17.70	20.10		
18.	5.74	6.20	350,000	460,000	15.90	20.40		
19.	5.60	5.80	280,000	360,000	12.40	16.00		
20.	5.70	6.01	300,000	350,000	13.30	15.60		

Table 4.11: 28Days and 56days concrete compressive strength of PKSC

S/n	Wt of cube(kg)		Crushing load(N)		Comp. Strength (N/mm^2)		Mean Comp. Strength (N/mm^2)	
	28days	56days	28days	56days	28days	56days	28days	56days
1.	6.01	5.72	500,000	450,000	22.20	20.00	19.80	23.40
2.	5.99	5.69	450,000	560,000	20.00	24.90		
3.	5.70	6.60	350,000	440,000	15.60	19.60		
4.	5.96	6.68	410,000	600,000	18.20	26.70		
5.	5.94	5.68	510,000	580,000	22.70	25.80		
6.	6.0	5.74	400,000	450,000	17.80	20.00		
7.	6.0	5.70	370,000	540,000	16.40	24.00		
8.	5.6	5.65	470,000	580,000	20.90	25.80		
9.	5.94	6.55	480,000	460,000	21.30	20.40		
10	5.92	6.58	480,000	570,000	21.30	25.30		
11.	6.02	5.66	520,000	470,000	23.10	20.90		
12.	5.98	6.54	510,000	550,000	22.70	24.40		
13.	5.78	6.68	460,000	450,000	20.40	20.00		
14.	5.98	5.71	350,000	590,000	15.60	26.20		
15.	5.96	5.72	400,000	580,000	17.80	25.80		
16.	5.96	5.67	500,000	600,000	22.20	26.70		
17.	5.98	6.59	430,000	550,000	19.10	24.40		
18.	5.80	6.65	450,000	580,000	20.00	25.80		
19.	5.9	6.70	480,000	460,000	21.30	20.40		
20.	6.00	5.72	370,000	440,000	16.40	19.60		

Table 4.12: Mean compressive strength of PKSC

S/n	Curing age (Days)	Mean Compressive strength (N/mm^2)	Standard Deviation
1.	3	11.50	1.14
2.	7	14.10	1.44
3.	14	15.20	1.39
4.	21	17.70	1.60
5.	28	19.80	1.45
6.	56	23.40	1.58

Table 4.13: Mean Compressive Strength of NWC (control)

S/n	Curing age (days)	Mean compressive strength (N/mm^2)
1.	3	12.34
2.	7	15.60
3.	14	16.21
4.	21	19.63
5.	28	23.28
6.	56	24.60

The graph in Figure 4.2 is the mean compressive strength of NWC and PKSC. It also shows that the NWC has a higher compressive strength than PKSC. A rise was observed generally as the curing age increases in both concretes.

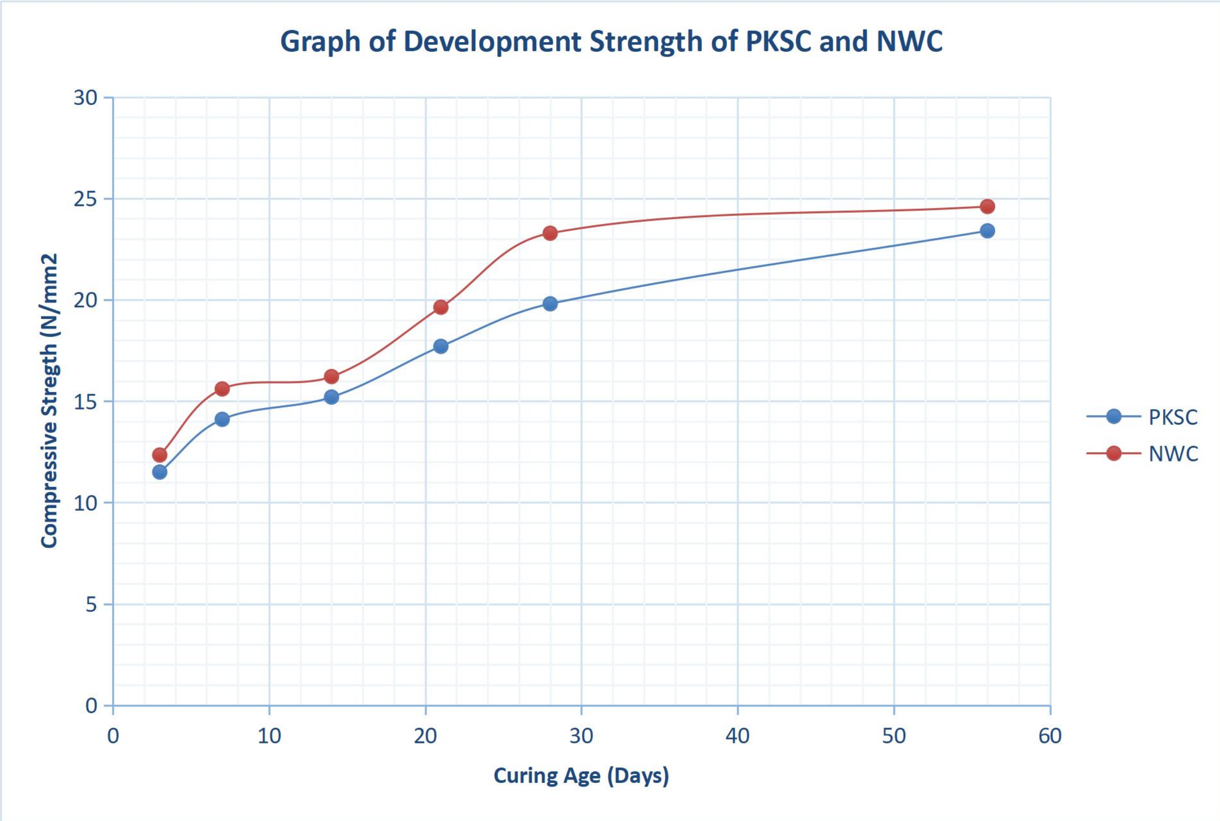

Figure 4.4: Graph of mean compressive strength of NWC and PKSC

4.1.5 Statistical analysis

Confidence interval (CI)

Confidence interval is computed from the statistics of the observed data. It gives a range of values for an unknown parameter. The interval has an associated confidence level that gives the probability with which the estimated interval will contain the true value of the parameter. Confidence interval CI can be computed from the expression;

$$CI = \overline{X} \pm Z \frac{S}{\sqrt{N}} \tag{4.1}$$

Where

C I = confidence interval

= N = Sample size

Z = Confidence level value

S = Sample standard deviation

$\overline{X} =$ Sample mean

4.1.6 Confidence Limits for the mean of compressive strength

Interval estimates are often desirable because the estimate of the mean varies from sample to sample. Instead of a single estimate for the mean, *a* confidence interval generates a lower and upper limit for the mean.

Confidence intervals can be estimated by using the table of the t- distribution. In this case, it can be estimated within specified limits of confidence the population mean $\overline{X}$. This is to confirm the authenticity of the mean of the compressive strengths determined from tests. The limits commonly used are the 95% and the 99% confidence limits.

For small sample theory, $N < 30,$ the confidence limits are calculated from the expressions below (Spiegel, 1972)

95% Confidence Limits are $\overline{X} \pm t_{0.975} S\sqrt{N-1}$ (4.2)

99% Confidence Limits are $\overline{X} \pm t_{0.995} \sqrt{N-1}$ (4.3)

In these expressions, $t_{0.975}$ and $t_{0.995}$ are percentage values for t- distribution, df degrees of freedom, where $df = N-1$.

The confidence limits for the mean of the compressive strengths determined are shown in Table 4.14. For each age of curing, the mean strength from test falls within the range of confidence intervals calculated for 95% and 99% respectively. This confirms that the mean strengths from the tests are true values.

Table 4.14: Confidence limits for Mean Compressive Strength

S/n	Curing age (Days)	Mean Strength	95% Confidence	99% Confidence
1.	3	11.63	11.08 and 12.17	10.88 and 12.38
2.	7	13.51	12.82 and 14.20	12.57 and 14.57
3.	14	15.23	14.56 and 15.90	14.32 and 16.14
4.	21	17.70	16.93 and 18.47	16.65 and 18.75
5.	28	19.73	19.03 and 20.43	18.78 and 20.68
6.	56	23.34	22.58 and 24.00	22.32 and 24.36

4.1.7 Confidence limits for standard deviation of compressive strength

Similarly, confidence limits for standard deviation are also used in confirming the authenticity of the standard deviation of the population. 95% and 90% are the commonly used; the interval can be defined for χ^2 -distribution. In the same way, it can be estimated within specified limits or interval of confidence the population standard deviation σ in terms of sample standard deviation S. This can be used to confirm the authenticity of the standard deviation of the compressive strengths determined from tests. For small sample theory, $N < 30$, the confidence limits are calculated from the expressions below Spiegel, (1972).

95% Confidence Limits are given by $\frac{S\sqrt{N}}{\chi_{0.975}}$ and $\frac{S\sqrt{N}}{\chi_{0.025}}$ (4.4)

The two values $\chi_{0.025}$ and $\chi_{0.975}$ represent respectively the 2.5 and 97.5 percentile values.

For the degree of freedom, $df = N - k,$ where $k = 1$ (the only parameter is S.D)

99% Confidence Limits are given by $\dfrac{S\sqrt{N}}{\chi_{0.995}}$ and $\dfrac{S\sqrt{N}}{\chi_{0.005}}$ 4.5

Where df is the degree of freedom, N is the number of samples and k is the number of parameters determined in the test and used in the calculation. Here only the standard deviation is the parameter calculated.

The confidence limits for the standard deviation of the compressive strengths determined are shown in Table 4.15. For each age of curing, the standard deviation for the failure compressive strengths from test falls within the range of confidence intervals calculated for 95% and 99% respectively. This confirms that the standard deviations for the failure compressive strengths from tests are the true values.

Table 4.15: Confidence Limits for Standard Deviation for Compressive Strength

S/n	Curing age (Days)	Standard Deviation	95% Confidence	99% Confidence
1	3	1.14	0.80 and 2.31	0.70 and 2.90
2.	7	1.44	0.91 and 3.26	0.76 and 4.14
3.	14	1.39	0.92 and 2.98	0.79 and 3.77
4.	21	1.60	1.21 and 2.94	1.00 and 3.61
5.	28	1.45	1.15 and 2.82	0.98 and 3.52

6.	56	1.56	1.19 and 2.89	1.05 and 3.58

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

.From the results of the physical properties of Palm Kernel shells it can be observed that the PKS possess properties that are suitable for LWC. However, there are other properties such as low density and gradual cracking due to ductility which are of more advantages compare to crushed granite. Hence, it can be concluded that PKSC has excellent physical properties and can be used as aggregates for structural elements.

Also based on the results of compressive strength from this research, PKSC met the strength requirement with reference to previous research finding that the compressive strength of PKSC ranges from 5 to 25N/mm^2 based on mix design by Okafor (1988). Hence, it can be concluded that PKSC is suitable to be used as structural elements such as beam, slab and column because of its low density and compressive strength which is above the minimum of 17.00N/mm^2 recommended by ASTM C330/C330-09.

5.2 Recommendations

PKS is recommended for use as aggregate for structural elements such as beam, slabs and columns due to its excellent properties.

Further studies are also recommended with other water cement ratio and mix ratio to evaluate their influences on the strength of PKSC, curing age of 90days and above should be allowed.

5.3 Contribution to knowledge

The thesis have been established that; Palm kernel shells can be used as aggregate for structural elements such as beam, slab and column.

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APPENDICES

Appendix A:

Concrete Mix Design

Step-1: Determination of water/cement ratio

Characteristic strength, assumed f_c =20N/mm^2 at age 28days

The margin M is calculated from the expression

$$M = K * S \tag{A.1}$$

Where $K = A$ defect percentage permitted below the f_C value

Then, $k = 1.64$ for 5% defect

S= Standard Deviation.

From Figure 1 (BS Standard)

$S = 8$ (For a less than 20 results)

$k = 1.64$ (5% Defects)

$M = KS$

$M = 8 \times 1.64$

$M = 13.2$

Step-2: Determinations of the strength

This is estimated from the expression;

$$f_m = f_c + M \tag{A.2}$$

$f_m = 20 + 13.2$

The mean target strength, $f_m = 33.2 N/mm^2$

The type of Cement is Ordinary Portland Cement (OPC). The fine aggregate is un-crushed and the coarse aggregate is crushed.

Then the free-water/cement ratio from table for (OPC) at age 28days and crushed aggregate is $49 N/mm^2$.

From the graph, the curve for $49 N/mm^2$ and 0.5 free water cement ratio is plotted and free-water cement ratio of 0.65 is obtained at the strength of $33.3 N/mm^2$.

Step-3: Water content

Maximum aggregate size is 10mm. If slump of 9mm is assumed then free water content can be obtain as follows;

For slump of 0 – 10mm and maximum aggregate size of 10mm and using un-crushed fine aggregate and crushed coarse aggregate of different sizes.

The free water content is estimated by the expression;

$$W = \frac{2}{3} w_f + \frac{1}{3} w_c . \qquad \text{(A.3)}$$

Where $w =$ free water content

$w_f =$ Free water content appropriate to type of fine aggregate.

$w_C =$ Free water content appropriate to type of coarse aggregate.

From the table,

$w_f = 150kg/m^3$, and $w_C = 180kg/m^3$.

Hence,

$$W = \left(\frac{2}{3}\times 150\right) + \left(\frac{1}{3}\times 180\right)$$

$$= (2\times 50) + (1\times 60)$$

$$= 100 + 60$$

$$W = 160kg/m^3.$$

Step-4: Cement content

This is calculated from the expression;

C $C =$ Free water content/ water-cement ratio

$$C = \frac{160}{0.65}$$

$$C = 246.15kg/m^3.$$

Step-5: Aggregate content

The relative density of aggregate from the preliminary test carried out in the laboratory is 2.4. Then from the BS graph of wet density of concrete mix against free water content, and the calculated free water content $= 160kg/m^3$. The concrete density is obtained as $2250kg/m^3$. The total aggregate content can be calculated by:

Total aggregate content $= D - C - W$ (A.4)

Where D = Concrete density, C = Cement Content, W = Free water content.

Hence, Total aggregate $= 2250.00 - 246.15 - 160.00$

$$= 1843.85 kg/m^3$$

The percentage passing 600μm sieve for the grading of fine aggregate is 60%. The proportion of fine aggregate can be obtained from the graph which is 38%.

Then, the fine and coarse aggregate content can be obtained from;

Fine aggregate content = Total aggregate content x proportion of fine aggregate

$$= 1843.85 \times \frac{38}{10}$$

$$= 700.66 kg/m^3$$

Coarse Aggregate Content = Total aggregate Content – Fine Aggregate

$$= 1843.85 - 700.66$$

$$= 1143.19 kg/m^3.$$

The quantities of materials per m^3 are as follows;

Cement $= 246.15 kg$

Water $= 161.00 kg$

Fine aggregate $= 700.66 kg$

Coarse aggregate $= 1143.19 kg$

The quantities of materials for 120 cubes of size $= 150 \times 150 \times 150$ are as follows.

Volume of trial mix for 25 cubes

$$= ((0.15 \times 0.15 \times 0.15) \times 120) + (25\%\text{contingencies of trial mix})$$

$$= 0.4050 + 0.0211$$

$$= 0.4261 m^3$$

The quantities for trial mix $= 0.4261 m^3$, in which;

Cement $= 104.88 Kg$

Water $= 68.18 Kg$

Fine aggregate $= 293.27 Kg$

Coarse aggregate $= 487.11 Kg$

Appendix B:

Determination of specific gravity of cement and aggregates

$$\text{Specific Gravity } = \frac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_1)} \tag{B.1}$$

Where,

W_1 = Weight of density bottle empty

W_2 = Weight of density bottle +Sample

W_3 = Weight of density bottle + Sample +Water

W_4 = Weight of density bottle + Water

Sharp sand

$W_1 = 33g$.

$W_2 = 48g$.

$W_3 = 92g$.

$W_4 = 84g$.

Crushed granite

$W_1 = 480g$.

$W_2 = 1492g$.

$W_3 = 2011g$.

$W_4 = 1366g$

Palm kernel shell

$W_1 = 480g$.

$W_2 = 942g$.

$W_3 = 1467g$.

$W_4 = 1360g$

Cement

$W_1 = 34g$.

$W_2 = 43g$.

$W_3 = 84g$.

$W_4 = 88g$

Using Equations 3.5 the specific gravities of Sharp Sand, Crushed Granite, Palm Kernel Shell and Cement are 2.5, 2.76, 1.301 and 3.0 respectively.

Appendix C:

Determination of bulk density of aggregates

Bulk Density was determined in this research using a Mould with the following dimensions:

Length $= 11.3cm$, Width $= 4.5cm$ and Depth $= 4.5cm$

Volume of Mould $= 228.8cm^3$

Bulk Density is given by equation 3.6

$$\text{Bulk Density} = \frac{\text{Weight of Sample}}{\text{Volume of mould}} \tag{C.1}$$

Where,

W_1=Weight of empty mould

W_2=Weight of mould + Sample

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

Volume of mould $= 0.002288\text{m}^3$

Sharp sand

$W_1 = 267.1g$.

$W_2 = 635.0g$.

$W_3 = (635 - 267.1)g$.

$= 367.9g$

$= 0.3679Kg$

Crushed granite

$W_1 = 611g$.

$W_2 = 3293g$.

$W_3 = (3293 - 611)g$.

$= 2682g$

$= 2.682kg$

Palm kernel shell

$W_1 = 267.1g$.

$W_2 = 396.5g$.

$W_3 = (396.5 - 267.1)g$.

$= 129.4g$

$= 0.1294kg$

Using Equations 3.2 the Bulk Densities of Sharp Sand, Crushed Granite and Palm Kernel Shell are 1650, 1545 and 634kg/m^3 respectively.

Appendix D:

Determination of water absorption capacity of aggregates

$$\text{Water absorption capacity} = \frac{(W_2 - W_1)}{W_1} \qquad \text{(D.1)}$$

Where,

W_1 = Weight of Sun dried sample.

W_2 = Weight of Sample after 1hr/24hrs immersion in water

$W_2 - W_1$ = Weight of water absorbed.

Palm kernel shell

1Hour

$W_1 = 1000g$

$W_2 = 1110g$

$W_2 - W_1 = 110g$

24Hours

$W_1 = 1000g$

$W_2 = 1215g$

$W_2 - W_1 = 215g$

Crushed granite

1Hour

$W_1 = 1000g$

$W_2 = 1006g$

$W_2 - W_1 = 6g$

24Hours

$W_1 = 1000g$

$W_2 = 1006g$

$W_2 - W_1 = 6g$

Using Equations 3.7 the percentage water absorption of PKS in 1hour and 24 hours are 11 and 21.5% respectively while the percentage water absorption of crushed granite in 1hour and 24 hours is 6%.

Appendix E:

Sieve analysis

Sieve analysis provides information on the gradation of aggregates.

Coefficient of Curvature (Cc) may be calculated as:

$$C_c = \frac{(D_{30})^2}{(D_{30})(D_{60})} \tag{E.1}$$

Coefficient of Uniformity (Cu) is given by equation 3.9

$$C_u = \frac{D_{60}}{D_{10}} \tag{E.2}$$

Where,

$D_{60} =$ Particle size at 60% finer

$D_{30} =$ Particle size at 30% finer

$D_{10} =$ Particle size at 10% finer

Fineness Modulus (FM) is calculated as the sum of the cumulative percent retained divided by 100:

$$FM = \frac{\left(\sum \text{Cumulative percent retained}\right)}{100} \tag{E.3}$$

Sharp sand

$D_{60} = 1.10$

$D_{30} = 0.513$

$D_{10} = 0.181$

$C_C = 1.3$

$C_U = 6.0$

$FM = 2.69$

Crushed granite

$D_{60} = 19$

$D_{30} = 20$

$D_{10} = 13$

$C_C = 1.6$

$C_U = 1.4$

$FM = 5.74$

Palm kernel shell

$D_{60} = 7$

$D_{30} = 9$

$D_{10} = 6.0$

$C_C = 2.0$

$C_U = 1.2$

$FM = 3.81$

Using equations 3.8, 3.9 and 3.10 Coefficients of Curvature (Cc), Coefficients of Uniformity (Cu) and Fineness Modulus (FM) respectively was computed for Sharp sand, Crushed Granite and Palm Kernel Shell.