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Crushing Strength and Physical Characteristics of Palm Kernel Shell Concretes

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Abstract
The Crushing strength and other properties of palm kernel shell concrete were investigated in this study. The palm kernel shells were partially used to replace crushed stone in the concrete. Three concrete mix ratios of 1:1½:3, 1: 2: 4 and 1: 3: 6 were used for the study with a water-cement ratio of 0.6 for each mix. The crushed stone were replaced at 100%, 80%, 60%, 40%, 20% and 0% by palm kernel shell aggregate. Mixing was done manually and the workability of each mix was determined using the slump test. The crushing strength of the concrete was determined at 7, 14 and 28 days for each mix. For 1: 1.5: 3 concretes, strength of approximately 20N/mm^2 was attained at eighty percent replacement of crushed stone by palm kernel shell aggregate. Moreover, strength of 20N/mm^2 was realized at forty percent replacement for 1:2:4 concrete and for 1: 3: 6 palm kernel shell concrete a strength of 16.5N/mm^2 was only attained at 20% replacement of crushed stone by palm kernel shell. Concretes with low palm kernel shell content yielded strengths suitable for structural construction. Palm kernel shell concretes had low workability at all mix proportions.

Keywords: Palm Kernel Shell, Crushing Strength, Workability, Crushed stone and Mix proportions.

1.0 Introduction
Palm kernel shell (PKS) is one of the waste products of palm oil tree found predominantly in the rainforest regions close to the coastal areas of Nigeria and other tropical countries. This material is derived from oil palm seeds; after extracting the useful seeds, the shells are left as waste. Malaysia, the largest oil palm exporting country in the world produces over 4 million tonnes of palm kernel shell (pks) as waste material. This causes a serious environmental hazard as they are stored in open fields. In southern part of Nigeria, palm kernel is found in nearly every home and on the rural streets of the region. The shell is seen as a non-useful product. It is only used as a source of fuel for domestic cooking in most areas. The shells are hard, durable and water resistant. In recent times research works have been aimed at using the palm kernel shell as concrete aggregates, since they possess hard characteristics as other coarse aggregates. Most researchers aim at determining whether palm kernel shell can be used as lightweight coarse aggregates in concrete

The high demand of concrete in the construction industry has drastically reduced the availability of natural stone deposits which serve as coarse aggregates. Moreover, the cost of these normal aggregates has become very high especially in the coastal areas where there are no good road networks to enhance effective transportation to the sites. This also hinders development especially within the local communities where people can hardly afford to purchase the aggregates for construction purposes. Therefore, there arises the need to source for cheap but good and readily available alternative materials to substitute the normal coarse aggregate. Palm kernel shells which are hard, durable and water resistant can wholly or partially replace gravel stones as coarse aggregates in concrete if test results on its concrete produce reliable results.

The main purpose of this study was therefore to examine the crushing strength and other characteristics of concrete made using palm kernel shells as coarse aggregates and also compare the properties of palm kernel shell concrete (PKSC) with those of normal concrete of similar composition. The physical and mechanical properties of the PKS and granite aggregates used were also determined.

The results of this study if satisfactory will promote the use of palm kernel shell as an aggregate in the production of low-cost concrete. This will be of immense benefits to the people living in the tropical areas where it is in abundance.

2.0 Literature Review

Johnson and Mahmuud (2008), posited that palm kernel shells derived from oil palm trees *(elacisguincensis)* can be used as coarse aggregate to produce light weight concrete (LWC) because of its hard characteristics. They further stated that palm kernel shell aggregate has a very low impact value compared to normal rock aggregates. The shells showed higher resistance against impact. Palm kernel shell concrete has a density reduction of about 22% compared to normal weight concrete. Neville (1996) also found out that its compressive strength was 12% lower compared to that of normal weight concrete. Abullah (2003) and Okpara (1990) attempted to use palm kernel shells (PKS) as coarse aggregate to replace normal crushed granite aggregates traditionally used for concrete production and finally came out with encouraging results.

Okafor (1988) stated that the failure of palm kernel shell concrete was generally governed by its strength and that because of the smooth and convex surfaces of palm kernel shells, they produced poor bond with the cement matrix. He also maintained that with the use of silica fume as plasticizers, palm kernel shell concrete achieved a high strength.

Ata et al. (2006) compared the mechanical properties of palm kernel shell concrete (PKSC) with those of coconut shell concrete and admitted that using PKS as light weight aggregate is more economical than using coconut shell.

They also posited that palm kernel shell consisted of 60 – 90 % particles in the range of 5 – 12.70mm. According to them, the specific gravity of PKS varied between 1.17 and 1.37, while the maximum thickness of the shell was found to be about 4mm. Lobo (2005) also posited that the density of PKSC varied in the range of 1700 to 2050kg/m^3 depending on factors such as type of sand and PKS content.

Teo et al. (2006) carried out some tests on reinforced palm kernel shell concrete beams to investigate their flexural behaviour and reported typical flexural failure of under-reinforced PKSC beams. The moment capacities of PKSC beams were found to be higher than the predicted values by between 4 and 35%. The ductility ratio (which is the ratio of ultimate deflection to the first yield deflection) was found to be in the range of 3 to 5 for PKSC beams.

Alenguran, Helmi and Jumaat (2008) investigated on PKS reinforced concrete beams and concluded that their moment capacities were higher than those of normal weight concrete beams by 3%. They also maintained that the failure mode for PKSC beams was ductile compared to the brittle failure of normal weight concrete beams. PKSC beams exhibited higher deflection under constant loadings while normal weight concrete beams failed in brittle manner without warning.

Ndoke (2007) confirmed that palm kernel shell aggregate could be used as a partial replacement for coarse aggregate in asphalt concrete. He stated that asphalt concrete with 100% palm kernel shell is suitable for highly trafficked roads with the same amount of bitumen.

3.0 Materials and Methods

3.1 Cement: The cement used for this study was the UNICEM brand of ordinary Portland cement. It was kept in a good and dry condition prior to use and was also in conformity with the requirements of BS 12, 1991.

3.2 Aggregates

3.2.1 Coarse Aggregate: The coarse aggregate used was crushed granite obtained from Crushed Rock Industries Nig. Ltd quarry at Akamkpa in Cross River State. It consisted of different sizes of particles as shown in Table1. The aggregates conformed to the requirements of BS 812: Section 103.1:1985.

3.2.2 Fine Sand: The fine sand was obtained from a stockpile of Julius Berger (Nig.) Plc which was ordered from Ikpa River in Uyo, Nigeria. The sand consisted of particle sizes as shown in Table 2. It conformed to the requirements of BS 812: Part 1: 1975.

3.2.3 Palm Kernel Shell: This was obtained from an oil palm mill at Ibiono Ibom local government area of Akwa Ibom State of Nigeria. It consisted of different sizes of particles as shown in the grain size distribution in Table 3 and Fig. 3.

3.2.3 Water: Clean potable water obtained from the civil engineering laboratory of University of Uyo, Nigeria was used for mixing and curing of the concrete specimens. The water conformed to the requirements of BS 3148.

3.4: Tests Performed

Tests performed included sieve analysis of aggregates, specific gravity test on aggregates, workability test – slump test on fresh concrete mix, water absorption test on concrete cubes and crushing strength test.

Different nominal mixes of 1:1½:3; 1:2:4 and 1:3:6 was adopted for the research at a water cement ratio of 0.6. Batching of the constituents was by volume and mixing was done manually. The granite coarse aggregate was respectively replaced with 0, 20, 40, 60, 80, and 100% of palm kernel shell.

3.5 Water Absorption Test on Concrete Cubes

The concrete cubes after casting were allowed to set. After twenty-four hours, they were demoulded, weighed and then immersed in water for twenty-four hours. They were then surfaced dried and weighed in air, to obtain their saturated weight (w_1). Thereafter the cubes were oven dried at a temperature of between 100 – 110^{0}C and the dry weight was determined as w_2. Thereafter, the percentage of water absorbed by each cube was calculated using eqn. 1

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$$\text{Percentage water absorption} = w = \frac{(w1 - w2) \text{ x } 100\%}{w2} \quad \text{.........................eqn. 1}$$

Where, w_1 = saturated weight and w_2 = dry weight.

3.7 Sieve Analysis
Sieve analysis was performed on the palm kernel shells, sand and coarse granite to the specifications of BS 882: 1975. Different sizes of the sieves were stacked in descending order of sizes and the measured quantity of the respective aggregate was placed on the topmost sieve. The sieve set was shaken vigorously for ten minutes using a mechanical shaker and the mass retained on each sieve was weighed and the necessary computations was carried out. The coefficient of uniformity of the different aggregates were determined using eqn. 2

$$Cu = \frac{D60}{D10} \quad \text{eqn. 2}$$

Where, Cu = coefficient of uniformity, D_{60} = the size of mesh that passes 60% by weight of the sample from the plot, D_{10} = the largest size of the smallest ten percent of the effective size. The specific gravity (Gs) was determined using eqn. 3

$$Gs = \frac{(w2-w1)}{(w4-w1)-(w3-w1)} \quad \text{eqn 3}$$

Where, w1 = weight of empty density bottle, w2 = weight of bottle and dry aggregate, w3 = weight of bottle, soil and water, w4 = weight of bottle when full of water only.

3.8 Concrete Mixing and Preparation of Crushing Test Cubes
Mixing of the concrete constituents was manually done until a uniform mixture was obtained. The freshly mixed concrete was cast into 150 x 150 x 150mm steel moulds. Each mould was cleaned, oiled and the concrete was cast in three approximately equal layers, each layer tamped 35 times with a 16mm diameter steel tamping rod. The specimen was placed in a moist and damp place for twenty hours before demoulding. After 24 hours, the cubes were demoulded and cured in a water bath until the test age.

3.9 Testing of Concrete Cubes for Crushing Strength
The test cubes were removed from the water at the test age and allowed to dry. Each cube was weighed and the weight recorded. They were then crushed using a DENNISON crushing machine. The peak crushing loads were noted and their crushing strength were subsequently computed using eqn. 4

$$fc = \frac{P}{A} \quad \text{eqn 4}$$

Where, f_c = crushing strength (N/mm^2), P = Peak load (N), A = Cross sectional area of cubes (mm^2).

3.10 Workability Test
The slump of each batch of concrete was tested using a 300mm high slump cone. Fresh concrete was put into the cone in three approximately equal layers, each layer tamped 25 times. The concrete was then struck off to level with the top of the cone. The cone was afterwards lifted upwards and the difference between the height of the slump cone and the subsided concrete gave the slump of the mix, and the measure of the workability of the concrete mix.

4.0 Results and Discussion
4.1 Sieve Analysis: The results of the grain size analysis for sand, palm kernel shells and coarse granite are respectively presented in Tables 2, 3 and 4. They are also plotted in Figures 2, 3 and 4 respectively. From the results the sharp sand has a particle size ranging between 0.075mm sieve and 2.36mm with 7.1% of the aggregate being retained on 0.075mm and 1.0% retained on the 2.36mm sieve. The crushed granite and palm kernel shells have their particle sizes ranging between 3.35mm and 28mm.
The fineness modulus of the sharp sand was 2.9, while that of palm kernel shell and crushed granite were 3.24 and 3.03 respectively. This indicated that the palm kernel shells were coarser than crushed granite. The PKS, coarse granite and sharp sand had coefficient of uniformities of 2.54, 2.67 and 5.00 respectively. This indicated that the PKS and crushed granite aggregates contained fine, medium and coarse gravels. They were well graded. The sharp sand also contained fine, medium and coarse sand and was also well graded.

4.2 The Physical Properties of Materials Used
The physical properties of the various materials used in this study are summarized in Table 1. It could be observed that palm kernel shell has a low specific gravity of 1.37 while crushed granite had a specific gravity of 2.62. This indicated that palm kernel shell is less dense than crushed granite.

Table 1: Physical Properties of Materials Used.

Materials	Property	Values
Cement	Specific Gravity	3.15
	Initial Setting Time	8 hours
	Final Setting Time	23 hours
Sharp Sand	Specific Gravity	2.05
	Coefficient of Uniformity	5.00
	Fineness Modulus	2.9
Palm Kernel Shell	Specific Gravity	1.37
	Coefficient of Uniformity	2.54
	Fineness Modulus	3.24
Crushed Granite	Specific Gravity	2.65
	Coefficient of Uniformity	2.67
	Fineness Modulus	3.03

4.3 Workability of Fresh PKSC

The slump tests on the different mixes are presented in Table 2. The result showed that all the mixes of palm kernel shell concrete were not quite workable. Most of the mixes presented zero slumps except the mixes that contained no palm kernel shell.

Table 2: Slump test results for different mixes.

Combination (%)		Water Cement Ratio	Slump (mm)		
PKS	Crushed Granite		1:1½:3	1:2:4	1:3:6
100	0	0.6	0	0	0
80	20	0.6	0	0	0
60	40	0.6	2	0	0
40	60	0.6	2	0	0
20	80	0.6	4	2	0
0	100	0.6	8	5	3

4.4 Water Absorption Test Results:

The results of the water absorption tests are presented in Tables 3, 4 and 5. The results revealed that palm kernel shell concrete absorbed more water than the normal weight concrete. This could be attributed to the presence of many pores and voids in palm kernel shell aggregate. This also resulted in low strengths of palm kernel shell concrete.

Table 3: Water Absorption Capacity for 1:1½:3 PKSC.

Aggregate Combination		Un-soaked Weight (Dry) (kg)	Soaked Weight after 24 hrs (kg)	Weight of Water absorbed (kg)	Percentage of Water Absorbed (%)
PKS (%)	Granite (%)				
100	0	6180	6390	210	3.4
80	20	6480	6680	200	3.1
60	40	6930	7120	190	2.7
40	60	7020	7195	175	2.5
20	80	7600	7760	160	2.1
0	100	7980	8135	155	1.9

Table 4: Water Absorption Capacity for 1:2:4 PKSC.

Aggregate Combination		Un-soaked Weight (Dry)	Soaked Weight after 24 hrs	Weight of Water absorbed	Percentage of Water Absorbed
PKS	Granite				
100	0	5850	6070	220	3.8
80	20	5878	6093	215	3.7
60	40	6806	7011	205	3.0
40	60	7123	7303	180	2.5
20	80	7410	7575	165	2.2
0	100	7930	8090	160	2.0

Table 5: Water Absorption Capacity for 1:3:6 PKSC.

Aggregate Combination		Un-soaked Weight (Dry)	Soaked Weight after 24 hrs	Weight of Water absorbed	Percentage of Water Absorbed
PKS	Granite				
100	0	5654	5889	235	4.2
80	20	5636	5861	225	4.0
60	40	5880	6100	220	3.7
40	60	5920	6110	190	3.2
20	80	6710	6885	175	2.6
0	100	7800	7965	165	2.1

4.5 Crushing Strengths

The results of the crushing strength test are presented in Tables 6 and Figure 6. The results indicated that the strengths of PKSC cubes depended on the percentage of palm kernel shell in the mix. The highest strength of 30.13N/mm^2 was obtained at 28 days age and 18.40N/mm^2 at 7 days age for 1: 1½:3 mix ratios with no palm kernel shell content. However, at 80% replacement of crushed granite with palm kernel shell, strength of about 20N/mm^2 was obtained at 28 days. With the 1:3:6 mix, the lowest strength of 21.40N/mm^2 at 28 days and 12.73 N/mm^2 at 7 days were obtained. For the 1:2: 4 mixes, the crushing strength of cubes were found to be in the range of 12.90 to 26.3N/mm^2. For the same mix, strength of 20N/mm^2 was obtained with 40% replacement of granite stones with palm kernel shells.

Table 6: Average Crushing Strength for PKSC.

Concrete Mix	% Combination of Coarse Aggregate		7th Day Strength	14th Day Strength	28th Day Strength
	PKS	Granite			
1: 1½ :3	100	0	10.04±0.12	12.55±0.14	16.44±0.10
	80	20	12.23±0.12	15.04±0.01	19.93±0.33
	60	40	13.13±0.17	16.28±0.16	21.00±0.10
	40	60	13.67±0.29	17.63±0.11	22.00±0.33
	20	80	14.37±0.25	17.96±0.05	23.02±0.11
	0	100	18.40±0.08	23.74±0.06	30.73±0.08
1: 2: 4	100	0	7.80±0.16	9.60±0.11	12.90±0.08
	80	20	9.33±0.12	11.66±0.08	15.20±0.08
	60	40	11.45±0.13	13.74±0.12	17.87±0.10
	40	60	12.20±0.16	15.25±0.04	20.00±0.08
	20	80	13.40±0.08	15.40±0.06	21.43±0.31
	0	100	16.03±0.12	19.56±0.10	26.30±0.08
1: 3: 6	100	0	5.73±0.12	7.40±0.00	9.43±0.12
	80	20	6.90±0.08	8.65±0.05	11.57±0.12
	60	40	8.10±0.08	10.45±0.14	13.40±0.10
	40	60	10.09±0.12	11.50±0.08	14.07±0.12
	20	80	10.09±0.10	12.41±0.13	16.53±0.12
	0	100	12.73±0.12	15.90±0.11	21.40±0.08

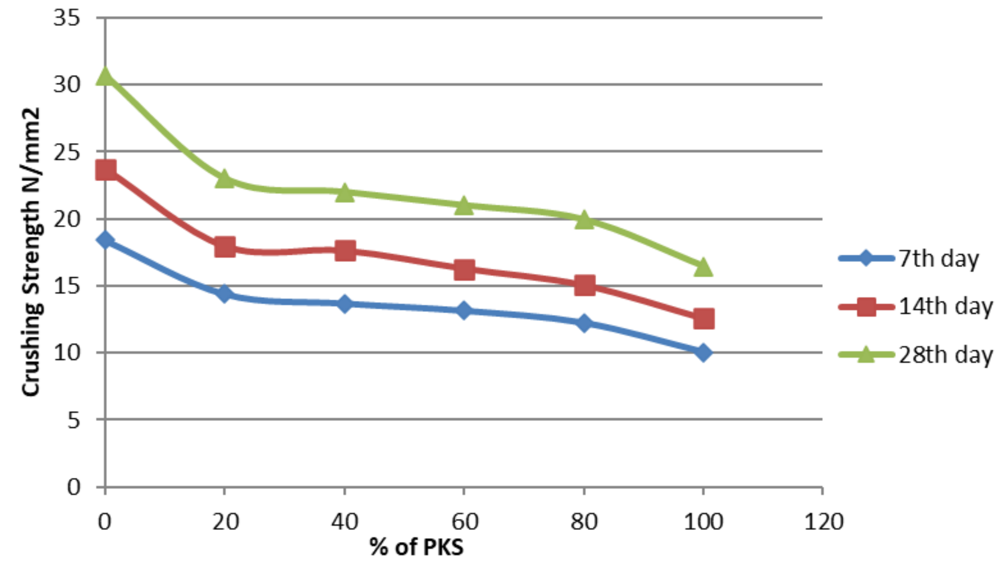

Fig. 5: Average Crushing Strength for 1:1.5:3 PKSC

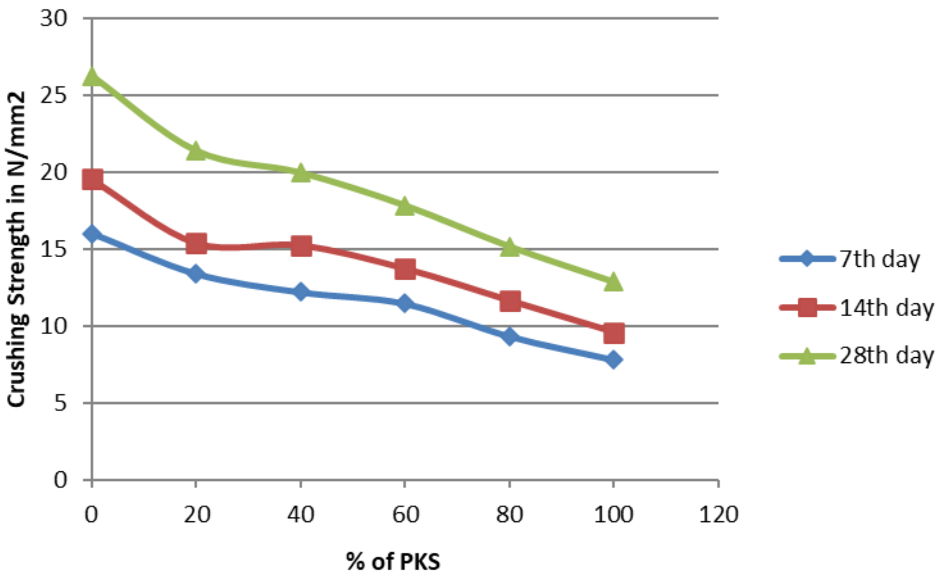

Fig. 6: Average Crushing Strength for 1:2:4 PKSC

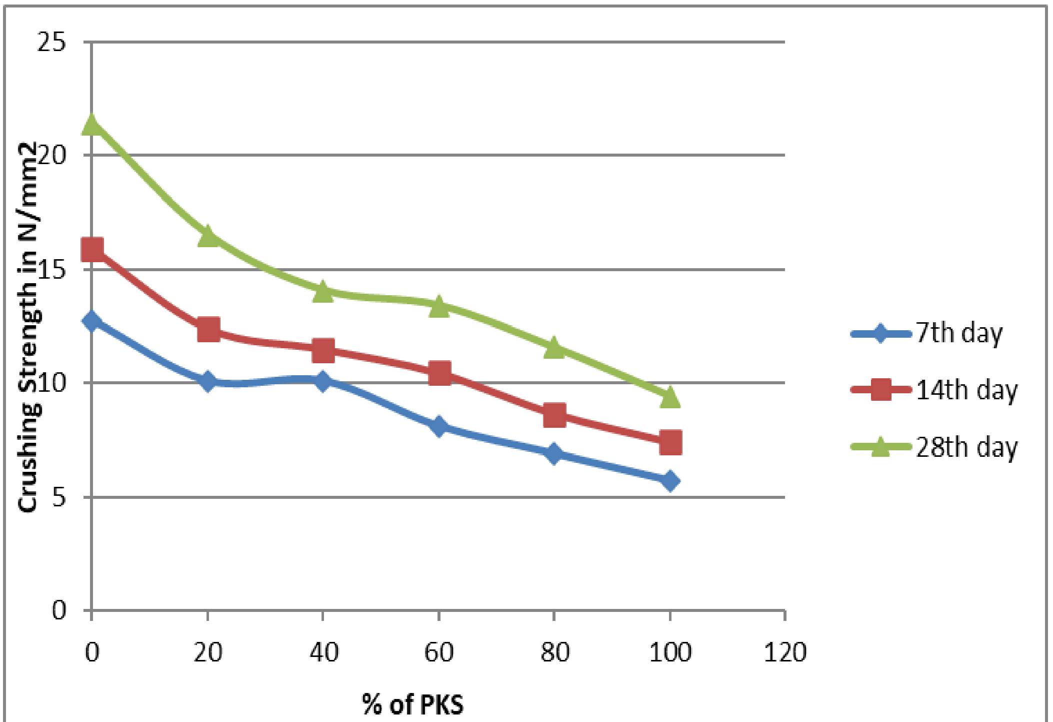

Fig. 7: Average Crushing Strength for 1:3:6 PKSC

4.6 Density Of PKSC: The average density of PKSC also varied depending on the percentage replacement of the granite with palm kernel shell as shown in Table 7.

Table 7: Average Density of PKSC.

Concrete Mix	% Combination of Coarse Aggregate		7th Day Density	14th Day Density	28th Day Density
	PKS	Granite			
1: 1½ :3	100	0	1870	1875	1870
	80	20	1956	1955	1956
	60	40	2108	2100	2108
	40	60	2131	2130	2131
	20	80	2291	2300	2327
	0	100	2397	2395	2397
1: 2: 4	100	0	1742	1740	1742
	80	20	1791	1785	1791
	60	40	2044	2045	2044
	40	60	2144	2144	2144
	20	80	2222	2225	2222
	0	100	2485	2480	2485
1: 3: 6	100	0	1706	1708	1709
	80	20	1733	1730	1727
	60	40	1760	1755	1751
	40	60	1807	1800	1802
	20	80	2029	2030	2030
	0	100	2345	2340	2338

Table 2: Grain Size Analysis for Sharp Sand.

BS Sieve Size (mm)	Weight Retained (g)	Percentage Retained (%)	Cumulative % Retained	% Passing
100	-	-	-	100.0
4.75	-	-	-	100.0
2.36	4.8	1.0	1.0	99.0
1.18	32.8	6.6	7.5	99.0
0.60	107.9	21.6	29.1	70.9
0.30	164.8	33.0	62.1	37.9
0.15	145.8	29.2	91.2	8.8
0.075	35.7	7.1	98.4	1.6
Pan	491.8	-	289.3	-

Total weight of sample = 491.8g

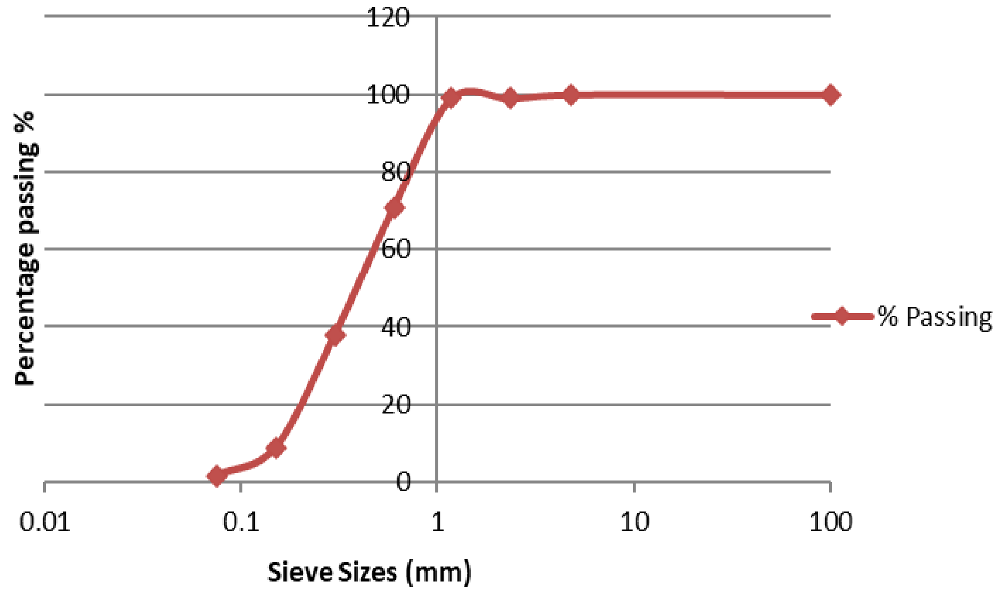

Fig. 2: Grain Size Analysis for Sand

Table 3: Grain Size Analysis for Palm Kernel Shell.

BS Sieve Size (mm)	Weight Retained (g)	Percentage Retained (%)	Cumulative % Retained	% Passing
50	-	-	-	100.0
37.1	-	-	-	100.0
28.0	4.8	1.0	1.0	99.0
19.0	86.8	17.4	18.4	81.6
14.0	108.9	21.8	40.2	59.8
10.0	176.8	35.4	75.6	24.4
6.3	73.7	14.7	90.3	9.7
3.35	4.27	8.5	98.8	1.2
Pan		-	324.3	-

Total weight of sample = 493.7g

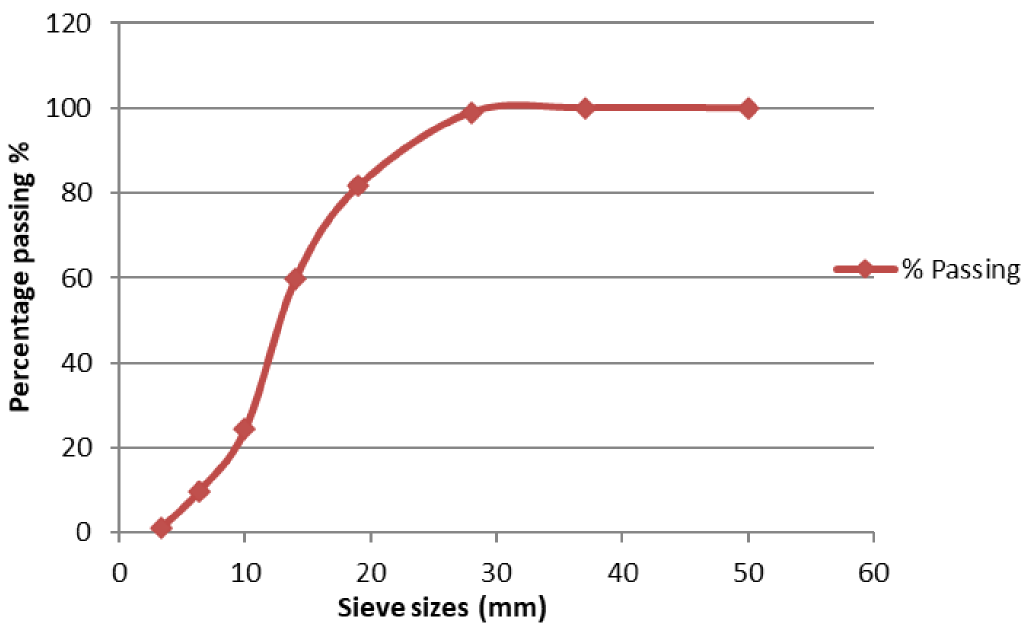

Fig. 3: Grain Size Analysis for Palm Kernel Shells

Table 4: Grain Size Analysis for Crushed Granite.

BS Sieve Size (mm)	Weight Retained (g)	Percentage Retained (%)	Cumulative % Retained	% Passing
50	-	-	-	100.0
37.1	-	-	-	100.0
28.0	5.6	1.1	1.1	98.9
19.0	92.8	18.6	19.7	80.3
14.0	125.6	25.1	14.8	55.2
10.0	162.8	32.6	77.4	22.6
6.3	70.6	14.1	91.5	8.5
3.35	34.6	6.9	98.4	1.6
Pan	495.0	-	302.9	-

Total weight of sample = 475.0g

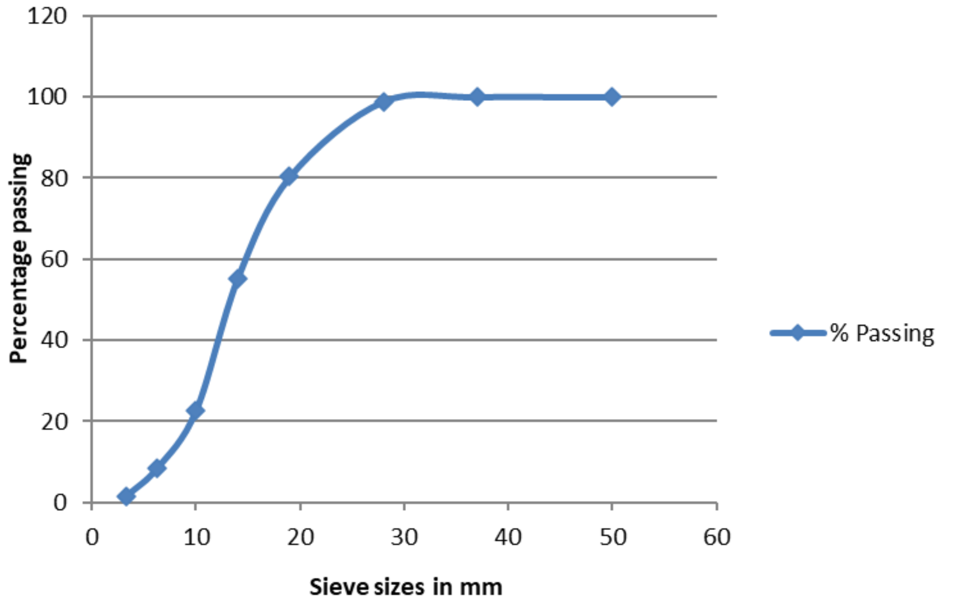

Fig. 4: Grain size analysis for crushed granite

Table 8: Proportioning of Aggregates per cubic metre of concrete.

Aggregate Combination			w/c ratio	Cement (kg/m³)	Sand (kg/m³)	PKS (kg/m³)	Crushed Granite (kg/m³)	Water (kg/m³)
Mix Ratios	PKS	Crushed Granite						
1: 1½ :3	100	0	0.6	524	843	1964	-	315
	80	20	0.6	524	843	1571	146	315
	60	40	0.6	524	843	1178	292	315
	40	60	0.6	524	843	785	441	315
	20	80	0.6	524	843	392	584	315
	0	100	0.6	524	843	-	731	315
1:2:4	100	0	0.6	412	914	2057	-	247
	80	20	0.6	412	914	1646	153	247
	60	40	0.6	412	914	1234	306	247
	40	60	0.6	412	914	823	460	247
	20	80	0.6	412	914	411	730	247
	0	100	0.6	412	914	-	766	247
1:3:6	100	0	0.6	286	960	2160	-	172
	80	20	0.6	286	960	1728	161	172
	60	40	0.6	286	960	1290	322	172
	40	60	0.6	286	960	864	488	172
	20	80	0.6	286	960	72	643	172
	0	100	0.6	286	960	-	806	172

5.0 Conclusion and Recommendations

From the results of the experimental investigation carried out the following conclusions were made:

With proper quality control, a 28th day compressive strength of 20N/mm2 can be obtained for 1: 1½ :3 and 1:2:4 palm kernel shell concrete at respective replacement of 80% and 40%.

Palm kernel shell concrete of 1: 1½: 3 mix attained strength more than 15% with no coarse granite content.

The workability of palm kernel shell concrete was very low, hence PKSC were stiff.

For all mixes, the strength of PKSC decreased with increase in palm kernel shell content.

PKSC with low percentages of PKS could be used for

foundation concrete of low-rise buildings and fence walls.
PKSC should be used for lean concretes and blinding concretes.
Higher water cement ratios should be adopted when using PKSC in order to produce workable concretes.

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