UTILIZATION OF PALM KERNEL SHELL (PKS) AS COARSE AGGREGATE IN LIGHTWEIGHT CONCRETE (LWC)

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Abstract - The increasing and high cost of building/construction of agricultural, industrial, residential and commercial structures in developing countries have raised concern to public and private developers thus resulting in alternative ways of subsidizing cost as well as maintaining the integrity of developed structures. Secondly, the problem of handling, managing and disposing of palm kernel shell (PKS) and other agro-waste materials from palm oil mills have equally triggered concerns which are predisposed on environmental sustainability. This research therefore tends towards producing a sustainable environment and an alternative in the construction industry by exploring the potential of the use of PKS as aggregate replacement in light weight concrete (LWC). The feasibility of PKS as aggregate replacement in LWC was achieved through compressive strength analysis, slump/concrete workability test, water absorption capacity test and density analysis respectively conducted on two mix ratios of 1:1:2 and 1:1.5:3 at 0%, 25%, 50%, 75% and 100% PKS replacement which were used to cast concrete cubes of dimension 150×150×150mm that were cured at 7, 14, 21 and 28 days respectively. It was observed that the PKS showed density of within 2000kg/m^3 with high water absorption capacity which are within acceptable limits for all the PKS replacements, but compressive strength and workability of the cubes decreased with increase in percentage PKS. The study also showed that PKS can replace granite/coarse aggregate for up to 50% for both mix ratios since all cubes tested with 50% PKS content exceeded 15N/mm^2 strength which is the minimum for LWC. Therefore PKS can be used only as a partial coarse aggregate replacement in concrete production.

Keywords: Lightweight concrete, palm kernel shell, compressive strength, coarse aggregates, concrete

1. INTRODUCTION

Concrete which is an admixture of water, aggregates (coarse and fine) and cement, is a heterogeneous construction material widely used in the construction industry and forms the basis for infrastructural development of any nation [13]. Concrete as a construction material is strong in compression and when reinforced with steel which is strong in tension, it becomes a durable material which can withstand various degrees of loading and can be formed into various shapes and sizes [1]. Basically every structure built and constructed in the tropics for both agricultural, industrial, commercial and residential purposes are executed extensively with the use of concrete and its derivatives respectively. However, the cost of concrete and other construction materials associated with its application and use in Nigeria are high and only affordable to individuals and corporations that have the wherewithal to pay for them so this hampers or reduces the rate of community development. To mitigate the high cost of construction materials such as concrete and demand for environmentally friendly construction materials, while also strengthening economic growth and competitiveness of agricultural wastes (palm kernel shells, coconut husks/shells, periwinkle shells e.t.c) as replacement materials in construction industry [16]. According to [15] and [8] other agricultural wastes like periwinkle shells have been used successfully as alternative material for coarse aggregate to partially replace crushed stones in concrete production.

According to [18] palm kernel shells (PKS) is derived from oil palm tree (*elaeis guinensis*) an economically valuable tree which is native to West Africa and widespread throughout the tropics. PKS is obtained as wastes or by-products of oil palm mills; they are hard in structure, irregular in shape and vary in size with thickness of 0.15 to 8 mm [2]. Environmental sustainability for human development is unsettled by the poor methods of disposal, management and handling of PKS and its associated derivatives which results in pollution and craves for alternative ways which will maintain environmental harmony and reduced emissions that are harmful. In Nigeria about 1.5 million tons of PKS are produced per annum predominantly within the coastal areas [11] while in south-east Asia, PKS is one of the most quantitative waste material produced with Malaysia producing approximately 4 million tons per annum [17], all these pose a threat to the environment if their disposal is mismanaged and poorly handled. Apart from using PKS as replacement for coarse aggregates in concrete they can be used as local fuels for domestic cooking, co-firing agents for boilers in oil mills and filler materials for filling pot holes in muddy areas [19];[18]..

The main objective of this study is to utilize PKS to replace coarse aggregates in lightweight concrete (LWC) at various proportions of 25, 50, 75 and 100% respectively after which comparative analysis will be carried out with concrete cubes of same dimensions to ascertain the reliability of PKS for construction purposes without jeopardizing the strength and integrity of the LWC.

2. MATERIALS AND METHODS

The following materials were used;

- Limestone Portland Cement
- Granite (coarse aggregates of 12mm).
- PKS (coarse aggregates of 12mm)
- Local river sand (fine aggregates of 5mm)
- Water.

2.1 Preparation of PKS

The PKS was sourced from a local palm oil processing factory and subjected to particle size distribution using a mechanical sieve shaker for at least 5minutes. After sieving the PKS was washed to remove oil/clay particles, air dried naturally and soaked in water for 24 hours under ambient temperature to obtain saturated surface dried aggregate (SSDA). The PKS was weighed accordingly using a mechanical weighing balance and used to replace coarse aggregates in concrete at 25%, 50%, 75% and 100% respectively.

2.2 Mix Proportions and Concrete Specimens

. Two mix ratios of 1:1:2 and 1:1.5:3 were used for the study on a factor of safety of 1.2 and water-cement ratio of 0.5. According to [3] and [11] the following relationships were used to develop the mix properties for the constituents and conditions of concrete since batching was carried out by weight.

$$Weight\ of\ Cement = Unit\ weight\ of\ concrete\ \times volume\ of\ cement \quad (1)$$

$$Weight\ of\ Sand = Unit\ weight\ of\ concrete\ \times volume\ of\ sand \quad (2)$$

$$Weight\ of\ coarse\ aggregate = Unit\ weight\ of\ concrete\ \times volume\ of\ coarse\ aggregate \quad (3)$$

$$Weight\ of\ water = Water - cement\ ratio\ \times weight\ of\ cement \quad (4)$$

(N/b: Unit weight of concrete = 2400 kg/m^3, Volume of Batch = 0.016m^3)

From the above relationships the mix design for the two mix ratios were obtained and are as expressed in Tables 1 and 2 respectively.

Table 1: Mix Design for Mix Ratio of 1:1:2

Constituent Material	0% PKS (Control)	25% PKS	50% PKS	75% PKS	100% PKS
Cement	9.6	9.6	9.6	9.6	9.6

Fine aggregate	9.6	9.6	9.6	9.6	9.6
PKS	0.0	4.8	9.6	14.4	19.2
Coarse aggregate	19.2	14.4	9.6	4.8	0.0
Water/cement ratio	0.5	0.5	0.5	0.5	0.5
Total water	4.8	4.8	4.8	4.8	4.8

Table 2: Mix Design for Mix Ratio of 1:1.5:3

Constituent Material (kg)	0%PKS (Control)	25% PKS	50% PKS	75% PKS	100% PKS
Cement	6.96	6.96	6.96	6.96	6.96
Fine aggregate	10.46	10.46	10.46	10.46	10.46
PKS	0.00	5.23	10.46	15.70	20.93
Coarse aggregate	20.93	15.70	10.46	5.23	0.00
Water/cement ratio	0.5	0.5	0.5	0.5	0.5
Total water	3.48	3.48	3.48	3.48	3.48

Based on the mix designs the concrete mix for both mix ratios (1:1:2 and 1:1.5:3) were produced at representative PKS replacements of 0%, 25%, 50%, 75% and 100% and subjected to a slump test to determine the workability of each mix for the various PKS replacements.

Plate 1: Slump Test for the Concrete mix

2.3 Casting, Curing and Testing of Cubes.

Standardized steel molds of dimension 150mm x 150mm x 150mm, oiled internally was used to cast concrete cubes for mix ratios of 1:1:2 and 1:1.5:3 representing the control(0%), 25%, 50%, 75% and 100% PKS replacements respectively. The filling of the molds were done in layers of approximately 50mm with each layer receiving 25 strokes of tampering rods to expunge air pockets, enhance settlement, compact and increase cohesion of the concrete constituents. After casting the molds were covered with polythene to control rate of evaporation and allowed to set for 24 hours. A total of twenty (20) concrete cubes were produced of which ten cubes each represented the two mix ratios, furthermore in each group of ten (10), two (2) cubes each represented the various replacements of PKS for various curing periods of 7, 14, 21 and 28 days respectively. After 24 hours of setting the cubes were demolded and moved to the curing tank for aging. Plates 2 and 3 below shows the demolded cubes and curing tank respectively.

Plate 2: Demolded concrete cubes

Plate 3: Curing Tank

At the required test age the cubes were removed from the curing tank, wiped off from the grit and weighed to determine their individual masses for computation of volume and water absorption test to ascertain ability of the particles to take in liquid due to porosity after being oven dried for 24 hours. The relationship for water absorption is as given by [14] as;

$$WA_C = \frac{Increased\ Weight\ or\ Wet\ Mass}{Dry\ weight\ of\ specimen\ or\ Dry\ Mass} \times 100\% \quad (5)$$

The cubes were aligned on the base plate of a universal testing machine and loaded at the rate of 15N/mm^2 per minute as specified by BS1881 until failure eventually occurred. The crushing strength was computed from BS EN 12390-3-2009 and [12] as;

$$f_c = F/A_c \quad (6)$$

Where f_c = Compressive Strength (MPa); F = maximum load at failure (N) and A_c is concrete cross sectional area (mm^2).

Plate 4: Crushing of Concrete cubes with the U.T.M.

A density test was also conducted on the cubes of both mix ratios (1:1:2 and 1:1:5:3) at the respective PKS replacements to ascertain their performance on compression.

3. RESULTS AND DISCUSSIONS

3.1 Particle Size Distribution.

Presented in Tables 3 and 4 are the summaries for the particle size distribution analysis carried out on both the PKS and crushed stones (granite). Also, Figures 1 and 2 also presents the graphical plots of the particle size distribution test carried out on PKS and crushed stones (granite).

Table 3: Result of PKS Sieve Analysis

Sieve size (mm)	Mass of empty sieve (g)	Mass of sieve + PKS	Weight Retained (g) W_1	Cum. Weight retained (g)	% retained (R_1) %	Cum. (%) retained ΣR_1	% passing ($100 - \Sigma R_1$) %
37.5	659.83	659.83	0	0	0	0	100
20	600.44	641.26	40.82	40.82	2.04	2.04	97.96
14	580.12	600.68	20.56	61.38	1.03	3.07	96.93
10	550.40	690.72	140.32	201.70	7.02	10.09	89.91
6.3	556.51	1657.37	1100.86	1302.56	55.04	65.13	34.87
4.75	569.81	969.95	500.14	1702.70	20.01	85.14	14.86
3.15	535.61	735.73	200.12	1902.82	10.01	95.15	4.85
2.36	535.61	614.21	78.60	1981.42	3.93	99.08	0.92
4.18	409.17	427.75	18.56	1999.98	0.92	100.0	0.00

Table 4.0: Result of granite Sieve Analysis

Sieve size (mm)	Mass of empty sieve (g)	Mass of sieve + coarse aggregate (g)	Weight retained (g) W_1	Cum. weight retained (g)	% retained R_1 (%)	Cum. % retained ΣR_1	% passing ($100 - \Sigma R_1$) %
37.5	659.83	659.83	0	0	0	0	100%
20	600.44	1064.04	463.60	463.60	11.59	11.59	88.41
14	580.12	955.62	375.50	839.10	9.38	20.97	79.03
10	550.40	2576.00	2025.60	2864.70	50.64	71.61	28.39
6.3	566.51	133.71	827.20	3691.90	20.68	92.29	7.71
4.75	569.81	865.41	295.60	3987.50	7.39	99.68	0.32
3.15	535.61	546.81	11.20	3998.70	0.28	99.96	0.04
2.36	535.60	536.80	1.20	3999.90	0.03	99.99	0.01
1.18	409.18	409.28	0.1	4000	0.01	100.00	0.00
Pan	418.68	418.68	0.0	4000	0.00	100.00	0.00

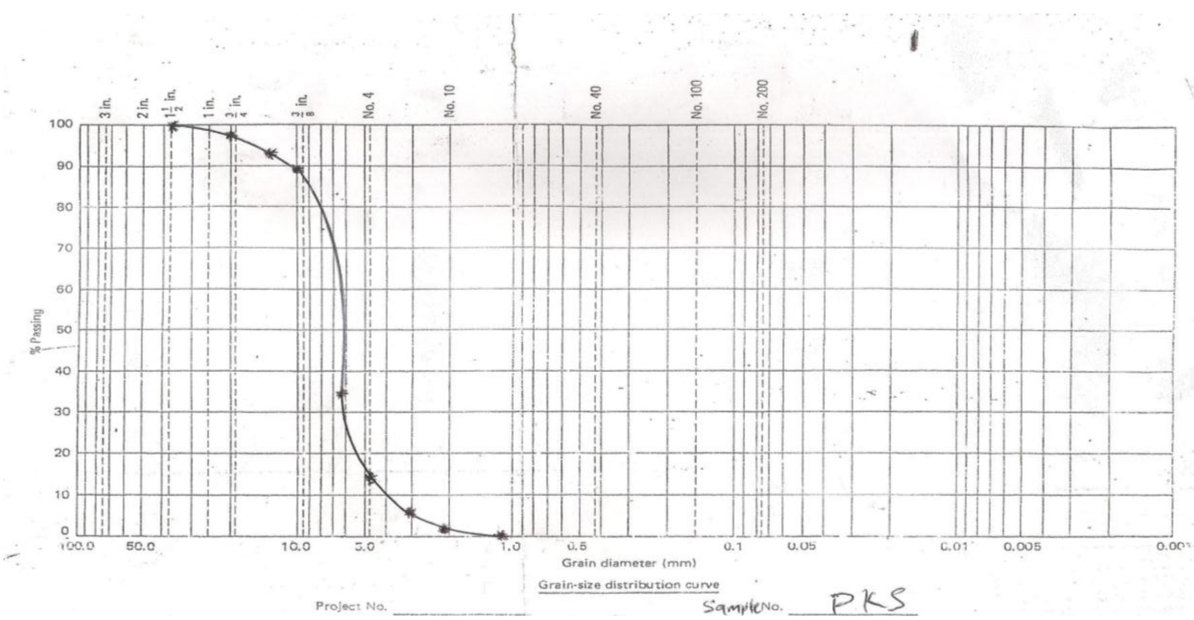

Fig. 1: Particle Size Distribution Curve for PKS

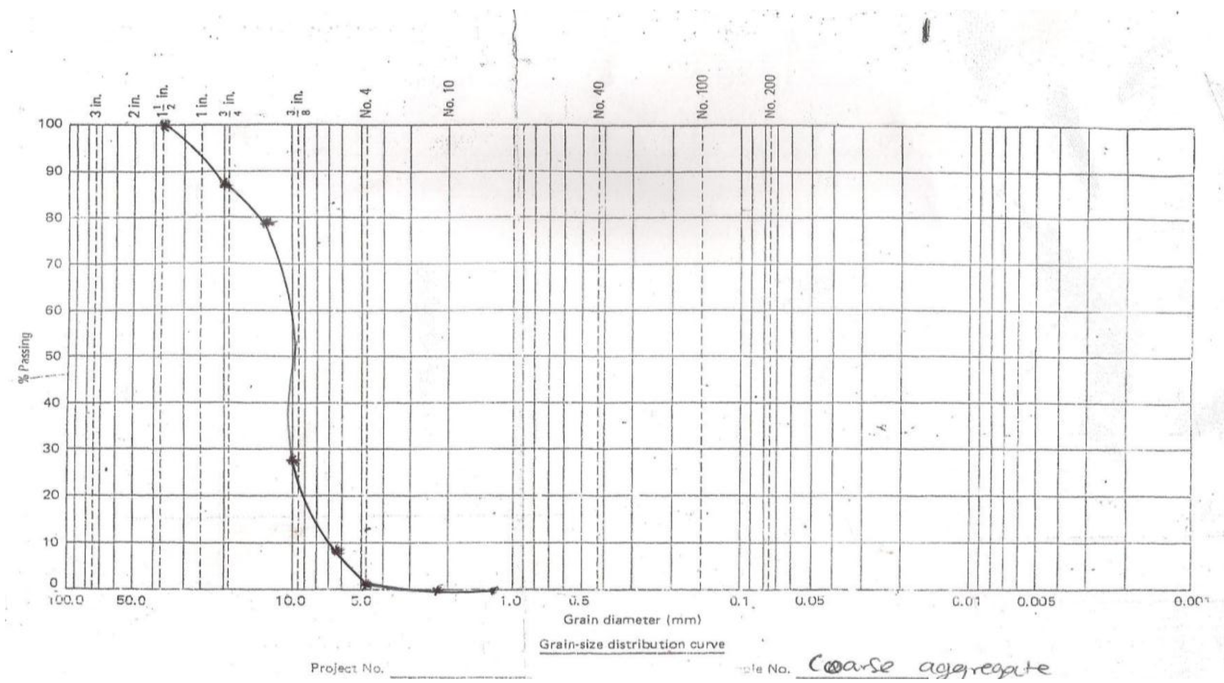

Fig. 2: Grain Size Distribution Curve for Crush Stone

From the graphical plots of both PKS and crushed stone the coefficient of uniformity (CU) and coefficient of curvature (CC) were obtained for PKS as 1.60 and 1.30 respectively while that of crushed stone yielded 1.40 and 1.42 respectively. According to [4] ; [3] and [10] which reports that grading must comply with the percentages of coarse aggregates which should fall within the limits of 1.00-2.30, this implies that the values obtained fall within range and are there well graded.

3.2 Slump Test

The results of the slump test carried out to determine the workability of fresh concrete are presented in Table 5 and Figure 3 below.

Table 5: Slump test values for both mix ratios

Mix Ratio	% of PKS and Crushed Stones	Slump (mm)
1:1:2	0/100	80
	25/75	50
	50/50	25
	75/25	20
	100/0	5
1:1.5:3	0/100	75
	25/75	40
	50/50	12
	75/25	10
	100/0	18

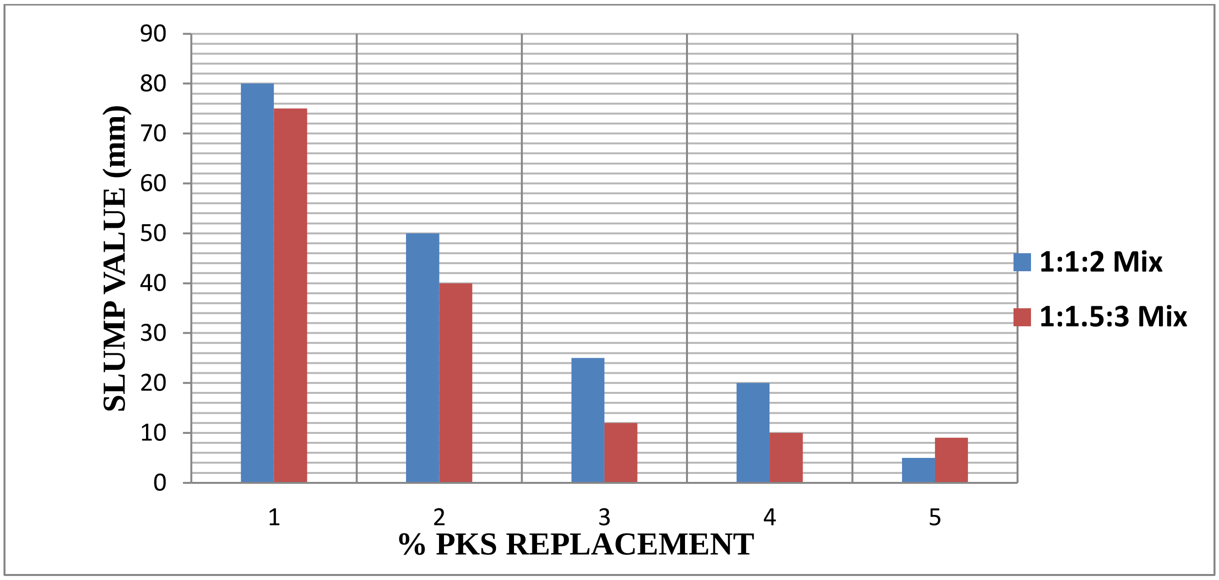

Fig. 3: Consistency of fresh concrete measured by slump test

The 0% PKS which represents the controls for both mix ratios yielded the highest slump values of 80 mm and 70 mm respectively while the slump values for various PKS replacements reduced as the PKS percentages increased. The highest slump value for PKS replacement for both mix ratios was obtained at 25% PKS replacement which was 50 mm and 40mm thus reflecting medium workability whereas the other values were less than 30 mm which is low workability. The results therefore imply that the workability of concrete reduced linearly as amount of PKS increased, because the normal aggregates used for concrete have a higher density and weight than PKS. Also, the specific surface area of PKS increases as PKS content increases which means that more cement paste is required for the lubrication of the aggregate hence reducing the fluidity of the mix, thereby reducing the height of slump. According to [7] the bonding between PKS and cement paste decreases with increase in higher percentage of PKS due to the smooth surface of PKS; this also affects and decreases the height of slump because of the collapse of the mix; also [12] reported a decrease in slump value for concrete when PKS was increased indifferent proportions. The results obtained also concurred with [9], which states that the workability of concrete decreases with the increment of PKS due to replacement percentage which causes the reduction in slump height.

3.3 Density and Water Absorption Test

The average density for both mix ratios were compiled and calculated for the curing periods (aging period) of 7, 14, 21 and 28 days and expressed in Table 6.0. The highest average density was observed from the controls (0% PKS) while the average density for the various % PKS replacements decreased with increment in PKS. At 100% PKS replacement the average density was 1507kg/m^3 and 1398kg/m^3 respectively; this shows that the density of concrete decreases with increase in PKS, and according to [9] the density of concrete decreases with increasing amount of PKS. From [3] the density range for the PKS shows that the concrete falls the range of density for light weight concrete which is <2000kg/m^3.

Table 6: Density Test Results for both Mix Ratios

Mix Ratio	% of PKS and Crushed stones	7days Weight (kg)	7days Density (kg/m^3)	14days Weight (kg)	14days Density (kg/m^3)	21days Weight (kg)	21days Density (kg/m^3)	28days Weight (kg)	28days Density (kg/m^3)	Average Density (kg/m^3)
1:1:2	0/100	7.68	2276	7.60	2252	7.7	2281	7.60	2252	2260
	25/100	7.46	2210	7.45	2207	7.8	2311	7.60	2252	2245
	50/100	7.00	2074	6.75	2000	7.0	2074	6.80	2015	2041

	75/100	6.12	1813	6.00	1777	6.00	1777	6.10	1807	1794
	100/0	4.82	1428	5.80	1719	5.00	1481	4.70	1393	1507
1:1.5:3	0/100	8:42	2495	8.20	2430	8.60	2548	8.3	2559	2508
	25/100	7.04	2086	7.10	2104	7.60	2252	7.20	2133	2144
	50/100	6.44	1908	6.20	1837	6.40	1896	6.20	1837	1870
	75/100	4.92	1453	5.00	1481	5.00	1481	4.70	1393	1453
	100/0	4.90	1452	4.80	1422	4.50	1333	4.68	1386	1398

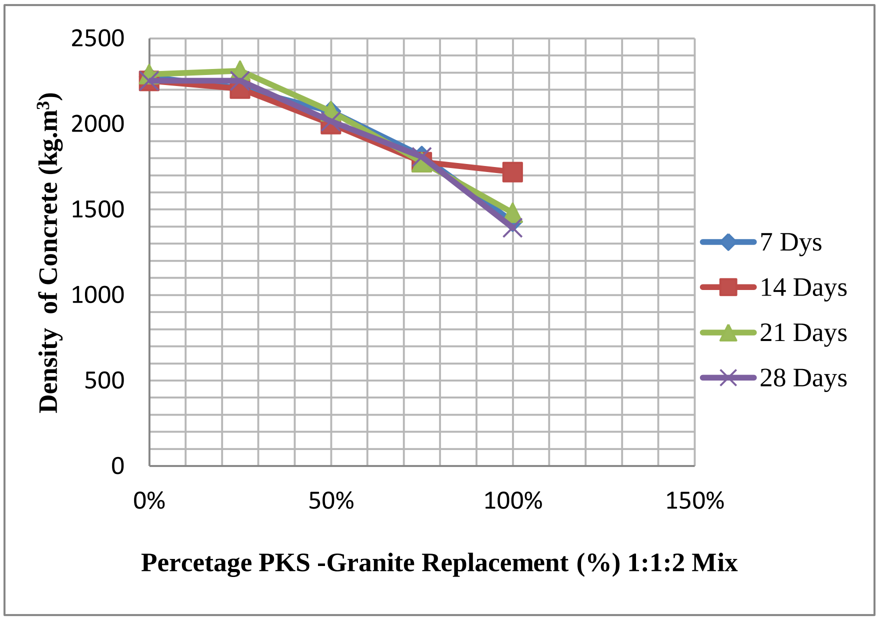

Fig. 4: Relationship between density and PKS replacement (1:1:2)

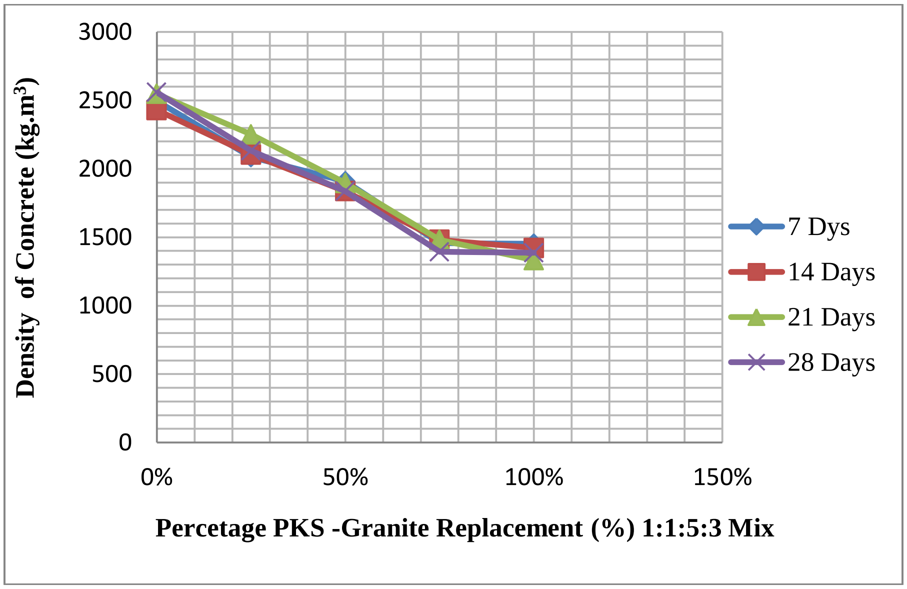

Fig. 5: Relationship between density and PKS replacement (1:1:5:3)

From the water absorption test carried out on all the cubes of both mix ratios it was observed that the rate of water absorption increased as the percentage of PKS replacement increased. This implies that the rate of absorption of the cubes is dependent on the level of porosity created by the increased level of PKS replacement. Also from the tests carried out on all the cubes all the absorptive capacities of the PKS concrete fell between 9-12.50% which is specified as okay by [6] and [3]. The water absorption test results concur with [9] which states that the inclusion of PKS in concrete increases the water absorption as well as the porosity thus resulting to higher amount of mixing water during concrete production. Table 7 shows the results of the water absorption rate of the various cubes.

Table 7: Water Absorption Test Results for both Mix Ratios

Sample No.	Wet mass (kg)	Dry mass (kg)	Water absorption%
C0	2.20	2.06	6.80
C25	1.98	1.80	10.00
C50	1.90	1.70	11.76
C75	1.82	1.62	12.35
C100	1.62	1.44	12.50
$C0_1$	2.0	1.88	6.38
$C25_1$	1.84	1.68	9.52
$C50_1$	1.78	1.60	11.25
$C75_1$	1.64	1.48	10.81
$C100_1$	1.56	1.40	11.43

3.4 Compressive Strength

The values for the compressive strength and force of the concrete cubes are summarized in Table 8 below.

Table 8: Compressive Test Results

Mix ratio	% of PKS/ % of Stones	7 days		14 days		21 days		28 days	
		Force	Strength	Force	Strength	Force	Strength	Force	Strength
1:1:2	0/100	448	19.91	528	23.47	538	23.91	708	31.47
	25/75	374	16.62	516	22.93	518	23.02	532	23.64
	50/50	364	16.18	492	21.87	498	22.13	522	23.20
	75/25	146	6.49	160	7.11	164	7.29	202	8.97
	100/0	20	0.89	54	2.40	54	2.40	82	3.64
1:1.5 :3	0/100	342	15.20	368	16.36	422	18:76	518	23.02
	25/75	338	15.01	362	16.09	374	16.62	450	20.00
	50/50	110	4.89	160	7.11	156	6.93	160	7.11
	75/25	18	0.8	18	0.8	30	1.33	62	2.70
	100/0	0	0	0	0	16	0.7	22	0.98

The controls (0/100) for both mix ratios exhibited the highest values for force and compressive strength during the curing period of 7-28 days. it can be seen that the compressive strength of cubes with 25% and 50% PKS replacement for the 1:1:2 mix ratio exceeded 15 N/mm^2 which is the minimum strength requirement for light weight concrete as specified by BS 8110. Also, the second mix (1:1.5:3) exceeded the 15N/mm^2 strength at 25% PKS. The highest strength of 23N/mm^2 was obtained at 28 days curing for 25% PKS replacement for both mixes suggesting that PKS can comfortably replace granite at 25% replacement, also PKS can replacement granite up to 50% using the first mix 1:1:2. The relationship between compressive strength, %PKS and curing age is represented in Figures 6, 7, 8 and 9 respectively.

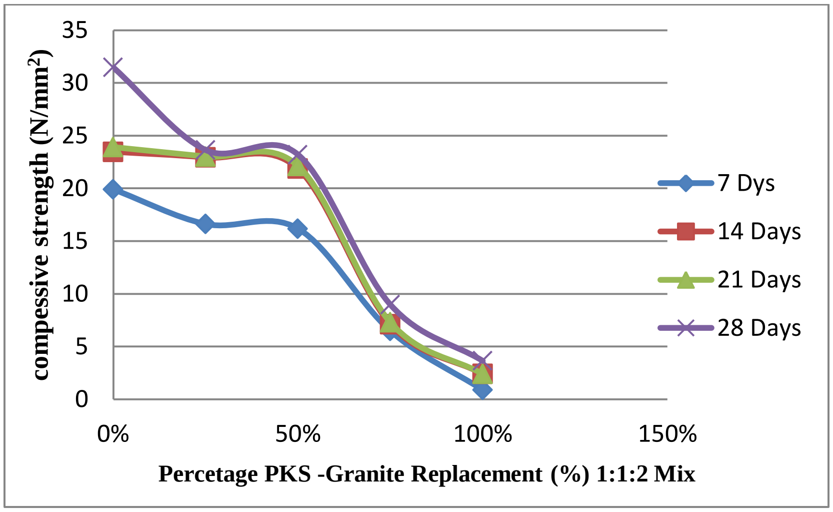

Fig. 6: Relationship between Compressive strength and %PKS

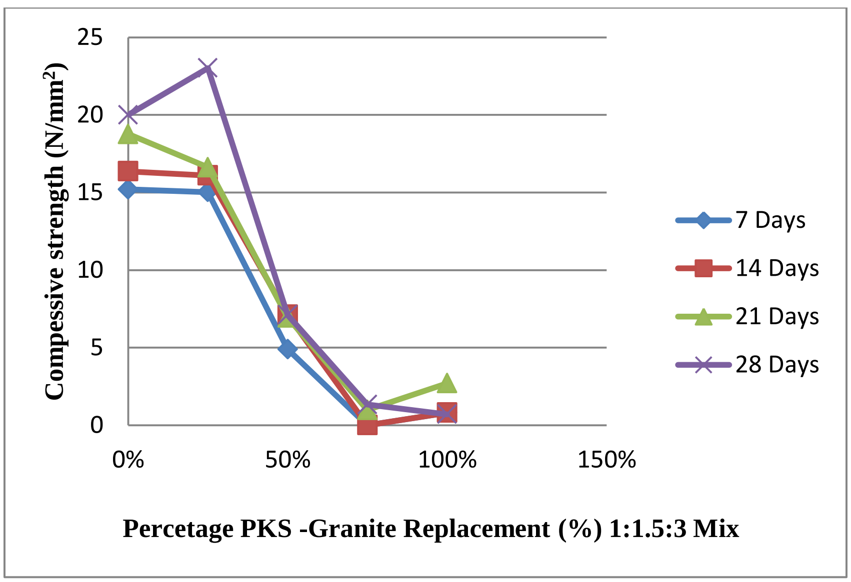

Fig. 7: Relationship between Compressive Strength and %PKS

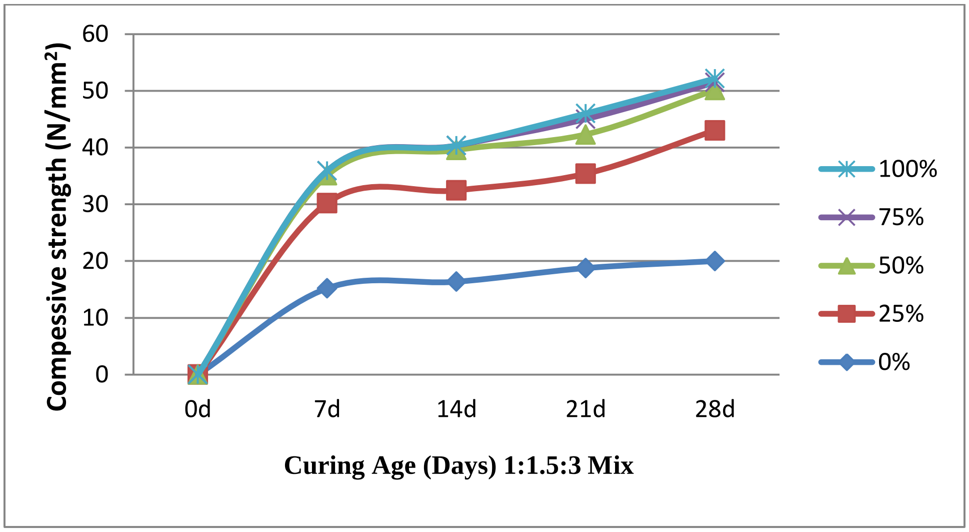

Fig. 8: Relationship between Compressive Strength and Curing Age

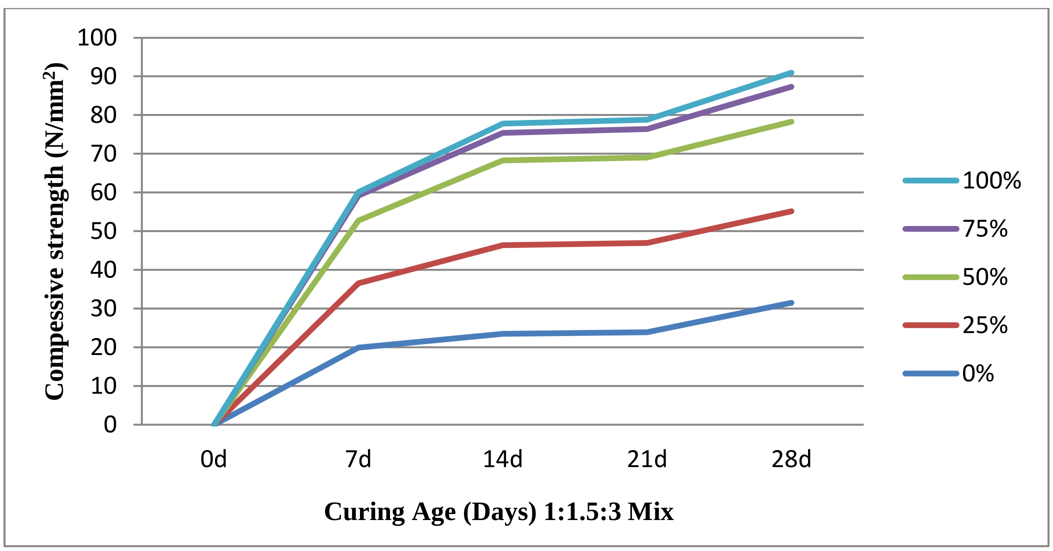

Figure 9: Relationship between Compressive Strength and Curing Age.

Figures 6 and 7 both mix ratios show that the compressive strength of concrete decreases as % PKS replacement increases. Similarly from Figures 8 and 9 both mix ratios also show that the compressive strength of the cubes increased as curing age increased due to increase in water absorption capacity which resulted in a higher crushing force for cubes. This result also conforms to [1]; [12]; [7] and [15], which states that values of compressive cube strength increases as the curing age increases and decreases as the % percentage PKS increases.

The 50% PKS replacement have values of 23.20N/mm^2 and 23.02 N/mm^2 for both concrete mix ratios of 1:1:2 and 1: 1.5:3 respectively at 28 days curing. This result is similar to findings by [9] and [14] who obtained result of 20.1N/mm^2 and 18.44 N/mm^2 at 25% replacement and 30% replacement respectively. Although it has been concluded that compressive strength decreases with increase in %PKS replacement, but from the study the 25% and 50% PKS replacements show acceptable values for lightweight concrete and this can be used for aesthetics and structural members with limited or lower loads.

4. CONCLUSIONS

The following conclusions were drawn from this study and they are stated as follows;

- The control concrete cubes (0/100) for both mix ratios showed acceptable values/limits for all the test values as indicated by BS 8110.
- The compressive strength of the concrete cubes decreased with increment in the percentages of PKS for both mix ratios of 1:1:2 and 1:1.5:3, but increased linearly with increase in curing age.
- The average density of the concrete cubes reduced with the increment of PKS, although the average densities of the 100% PKS replacement for both mix ratios yielded 1507kg/m^3 and 1398kg/m^3 which fall within acceptable limits for lightweight concrete.
- The workability of the concrete for both mix ratios decreases with the increase in %PKS replacement due to low density and poor bonding between PKS and coarse aggregates in concrete mix.
- The water absorption capacity of the cubes increased with the increase in %PKS replacement for both mix ratios.
- Although the general compressive strength of concrete decreases with increase in %PKS, the 25% and 50% of 1:1:2 ratio as well as 25% of 1:1.5:3 ratio from this study show acceptable values for construction so can be used as partial replacement in concrete production.

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