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PALM-KERNEL SHELL CONCRETE FOR STRUCTURAL USE - A PRELIMINARY INVESTIGATION

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ABSTRACT

The paper reports on the results of an investigation into the physical and strength characteristics of concrete (normlnal mixes), which contains crushed palm-kernel shell as fine aggregates instead of normal river sand. 66 No beams of 100mm x 100mm x500mm sizes and 396 No 100mm cubes as well were tested with varying mix ratio, palm-kernel/normal sand ratio and curing periods. The percentage content of palm-kernel shell in the aggregate varied from 0 to 100% in steps of 10%. The result of the investigation with mix 2:3:6 at 28 days gives 33N/mm^2 at 10% palm-kernel and 16N/mm^2 at 100% palm-kernel shell content, indicating that strength decreased with increase in palm-kernel content. Also, the strength characteristics of 100% palm-kernel shell concrete are found to be 16N/mm^2, 7N/mm^2, and 6N/mm^2 for 2:3:6, 1:2:4 and 1:3:6 mixes respectively implying that palm-kernel shell may be considered wholly or as partial replacement of river sand in concrete for non-load-bearing structural elem nts.

KEY WORDS: Slump, density. Gradation, compression, and flexure.

INTRODUCTION

As a result of high cost of construction and construction materials especially in Nigeria and other developing countries, different efforts have been made to find alternative local building materials to substitute wholly or partly some of the constituents of concrete. Examples are the researches on laterized concrete ((Balogun and Adepegba, (1982); Salau and Balogun, (1990); Osunade and Ogundeko, (1992); Obajimi, (1989)). The economic consideration for the possible use of lateritic material involved its mining from the ground as against the hectic collection of normal sharp sand from the rivers and riverbeds.

Chukwuani (1987) investigated the effect of sawdust ash in the strength of concrete and found the use of sawdust ash in partial replacement Of cement very successful in works where strength is not such an important factor. Recent researches may show the possibility of other types (other than lateritic materials) of fine/coarse aggregate such as periwinkle, coconut shells and palm-kernel shell. Palm-kernel shell occurs in commercial quantity in the three eastern states of Nigeria. The states account for about 65% of the total national output of palm produce.

According to the Federal Ministry of Agriculture and Natural Resources (FMANR) Joint Planning Committee (1974), the production, however, dropped as a result of civil war. The Western and Lagos States account for 30%, the remaining 5% is being produced in the Northern
States by Kwara, Sokoto, Plateau and Benue States. The most common species in Nigeria are Bura and Tenera which were adopted in the 1950s by the former West Africa Institute for Oil Palm Research (WAIFOR) now Nigerian Institute for Oil Palm Research (NIFOR).

Due to economic situation n Nigeria, the cost of conventional sand continues to rise on daily basis, and if palm-kernel shell is found suitable, the cost of concrete production and construction ay be reduced by about 85%. This paper reports on experimental investigation on physical and strength properties of concrete with varying percentages of palm-kernel shell as substitute in fine aggregate as well as different mix proportions.

SOURCES OF PALM-KERNEL SHELL

The fruit of the oil palm is a dupe; the outer pulp of which provides palm oil for commerce. Within the pulp or mesocarp lies a hard-shelled nut containing the palm kernel that provides two further commercial products; palm-kernel oil and the residual livestock food, palm-kernel.

For shell extraction, the matte coming from the centrifuges or presses consists of nuts and moist fibre with some residual oil. To extract the shell, it is necessary to

i. extract the nut from the fibre
ii. crack the nuts
iii. separate the kernel from the cracked shells

Hartley, (1967) explains further processes of fibre and shell separation. Methods of separation can be manual, hydraulic, pneumatic or mechanical.

PHYSICAL EXAMINATION OF PALM-KERNEL SHELL

Ogedengbe, (1985) states that palm-kernel shell when used in water treatment does not absorb appreciable quantity of water and neither does it swell nor rot. It has a specific gravity of about 1.325 ± 0.002, effective size (D_{10}) of 0.98mm and a uniformity coefficient of 1.63 when crushed. It is also very durable with a durability of 96.6%. When used as filter media, it absorbs colour and taste and removes excess acid from water. By weight, shell in the fruit is found to vary according to species. For example, in the specie Dura, it is 25 to 55% while in the specie Tenera, it is 1 to 32%.

Visual examination of crushed palm-kernel shell shows it to be as fine as the conventional river sand. It is, however, lighter in weight when compared with river sand, indicating that the density of concrete made with palm-kernel shell will be less compared with the density of sand concrete with the same volume. It is also gritty when rubbed between fingers.

EXPERIMENTAL PROCEDURE

For preliminary tests to determine physical properties of concrete made from palm-kernel shell, grading of the shell, moisture content absorption capacity, specific gravity, unit weight durability and slump tests were carried out. The palm-kernel shell used in this investigation was obtained from Centrolux Farm Limited, Olowo Village, Ogun State and villages around Ile-Ife and Modakeke towns, while the cement is Ordinary Portland Cement per BS 12 (1978) collected from the Ewekoro Factory in Ogun State of Nigeria.

For the compressive strength and flexural properties of concrete elements with palm-kernel shell as part of the constituents, the coarse aggregate used was crushed granite with density of 2650kg/m^3 and maximum diameter of 19mm. The fine aggregate was made of palm-kernel shell and normal

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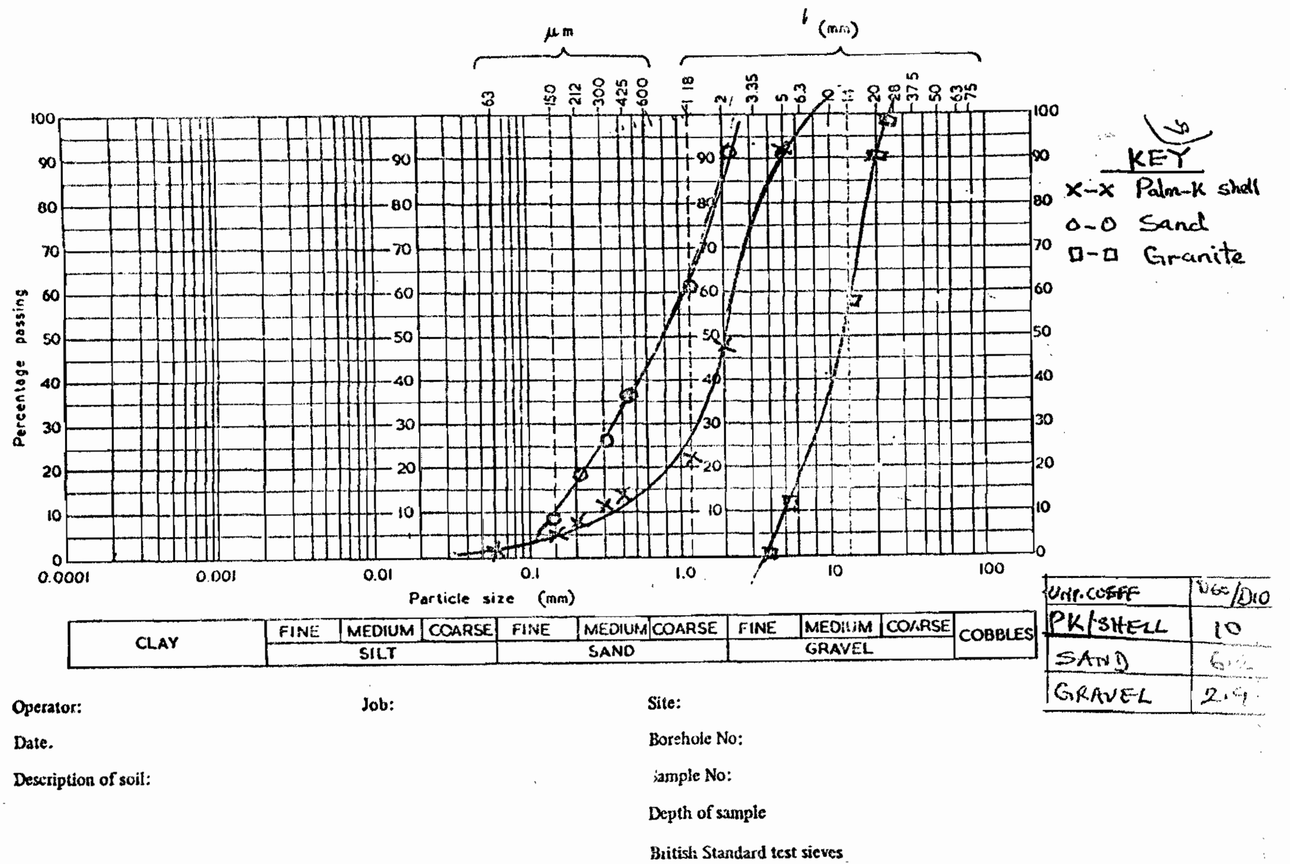

Fig. 1: Particle size distribution curve for palm-kernel shell, sand and granite.

river sands. Figure 1 shows the grading curves of all the aggregates.

The percentage of palm-kernel shell by weight of the total fine aggregate was varied in steps of 10% up to a maximum of 100%. Normal concrete contained 0% palm-kernel shell. Varying concrete mixes (cement: palm-kernel shell/normal sand: granite) of 2:3:6; 1:2:4: and 1:3:6 with corresponding water/cement ratio of 0.55, 0.65 and 0.75 to obtain normal consistency according to Reynolds and Steedman (1974) were used. In all, 396 cubes with varying curing periods, mix ratio and palm-kernel shell/normal sand ratio were tested for physical and strength characteristics.

66 No plain beams of 100mm x100mm x500mm were tested, two samples corresponding to the same palm-kernel shell content, mix proportion and water/cement ratio. The cubes were immersed in water of about 27°C temperature for different curing periods of 7, 14, 21 and 28 days, at the end of which they were removed and allowed to drain for 2 hours before testing. The beams were cured under damp sand for 3 days and kept in the laboratory environment until tested at 28 days.

The cube crushing tests were performed on ELG Budenberg compression machine with maximum capacity of 600kN while the beams were tested on simply supported span of about 450mm on third point loading in increment of about 5kN using Universal Avery testing machine with maximum capacity of 1000kN. To determine the deflection under loading, dual gauges were placed at the bottom face at the midspan of the beam and readings were taken before and after each load increment. During the testing, development of crack, mode of failure, ultimate failure load and its corresponding central deflection were noted and recorded for each mix.

RESULTS AND DISCUSSION

Physical Properties

The results of the sieve analysis of the aggregates presented in figure 1 show that palm-kernel shell has particle size ranging between 63 micron and 4.75mm just as normal sand. With uniformity coefficient of about 10.0, the palm-kernel shell is not considered to be uniform.

The natural moisture content varies between 10.5% and13.6% while the average specific gravity of the shell is 1.33 and absorption capacity, 9.5%. Clay shows specific gravities of 2.08- 2.72 typically for many British soils (Head; 1980) and as such palm-kernel shell can be classified as lightweight aggregate. The unit weight of palm-kernel shell is 1.23g/ml. With a durability value of 96%, the palm-kernel shell is quite durable, hence, it is not likely to be easily decay or rot in concrete.

Table 1 shows the values of the slump with different mix proportions and percentage content of palm-kernel shell: higher values are obtained for mix of 1:3:6 with water/cement ratio of 0.75 compared to others. No particular trend is observed for the same mix, with increase in percentage of palm-kernel shell. For percentage content of palm-kernel shell between 0 and 10, the slumps for all mixes showed almost the same values as for 100% palm-kernel shell content. All the slumps obtained are normal; with values between 9mm and 30mm. The results of the slump tests for the mixes showed that 1:3:6 had generally higher slump followed by the mix 1:2:4 and lastly 2:3:6. This may not be unconnected with the higher water/cement ratio of mix 1:3:6 (0.75) compared to those of mixes 1:2:4 (0.65) and 2:3:6 (0.55) respectively. Generally, workability is medium and based on this, the palm-kernel shell concrete can be suitable, just as normal sand concrete.

There is no particular trend in the densities of palm-kernel shell concrete with increasing age for all the percentage content of palm-kernel shell. There is also insignificant variation in the density of palm-kernel shell concrete with increase in percentage of palm-kernel shell content in the concrete just like conventional sand concrete. This shows that palm-kernel shell is a lightweight aggregate and should be suitable for use in non-load-bearing structural elements.

Compressive Strength

The values of the average cube strength for all the mix proportions, corresponding water/cement ratios and varying percentage contents of palm-kernel shell are summarized in Table 2. The compressive strength/age characteristics of different mix proportions for normal sand and palm-kernel shell content are shown in figures 2 and 3 respectively.

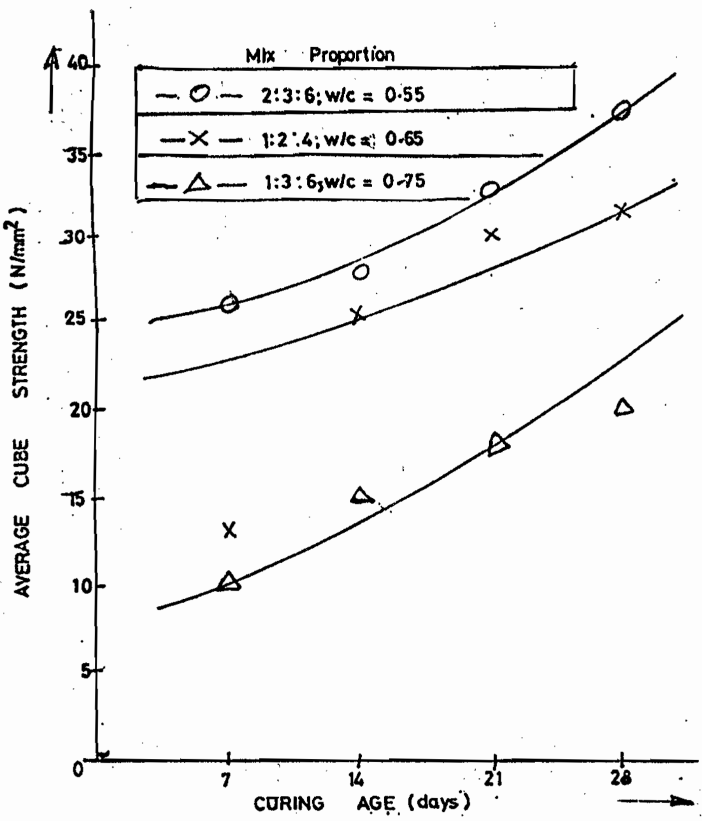

Fig. 2: Compressive strength-age characteristics of different mix proportions for normal sand concrete (0% palm-kernel shell)

For a given mix proportion, the increase in percentage of palm-kernel shell content is accompanied with reduction in cube strength. The reason for this could be attributed to the harshness of the mix with respect to increase in the shell content and lack of adequate bonding between shell particles and cement which had adverse effect on workability. However, there is an increase in the strength with increase in curing age. With a mix proportion of 2:3:6 and water/cement ratio of 0.55, the average cube strength normal sand concrete at 28 days was observed to be 37.2N/mm^2 while for the same mix proportion and water/cement ratio, the palm-kernel shell concrete cube strength at 28 days was 15.9N/mm^2, showing decrease of 57 3%. This indicates that the cube strength of palm-kernel shell concrete is less than half of the strength of the normal sand concrete. This may be attributed to the lower value of bond strength between the shell and cement when compared to normal sand and cement with adequate bond strength between them.

Figures 2 and 3 show that the rate of strength development with age is similar for all mixes considered. About 60% of the

Table 1: Values of Concrete Slumps with varied percentage of Palm-kernel Shell Content.

% Palm-kernel content	Slump (mm) with mix proportion. 2: 3: 6	Slump (mm) with mix proportion. 1: 2: 4	Slump (mm) with mix proportion. 1: 3: 6
0	9	17	30
10	9	17	29
20	10	18	27
30	9	18	28
40	10	19	28
50	9	18	27
60	9	16	29
70	10	19	28
80	10	18	29
90	10	19	30
100	9	21	30

Table 2; Variation in Density and Compressive Strength with % Palm-kernel Shell Content.

		Average density with mix proportion* (Kg/m³)			Average cube strength with mix proportion* (N/mm²)		
% p/k shell content	Age of concrete cube (days)	2:3:6	1:2:4	1:3:6	2:3:6	1:2:4	1:3:6
0	7	2350	2500	2430	26.0	13.5	10.4
	14	2450	2480	2500	27.8	25.6	15.4
	21	2450	2350	2450	33.0	30.0	18.5
	28	2380	2530	2430	37.2	31.5	20.1
10	7	2300	2420	2400	25.4	12.8	9.9
	14	2400	2350	2450	27.1	22.2	14.7
	21	2400	2300	2360	31.8	28.3	16.9
	28	2320	2400	2410	33.0	29.7	18.7
20	7	2400	2350	2380	25.0	10.9	8.5
	14	2400	2280	2430	26.8	20.9	14.5
	21	2300	2300	2250	30.6	26.1	16.3
	28	2300	2330	2350	32.2	28.0	18.7
30	7	2350	2300	2350	21.4	10.9	8.0
	14	2350	2300	2400	26.0	17.8	14.0
	21	2310	2300	2300	27.4	25.1	15.3
	28	2350	2300	2350	30.4	25.4	15.9
40	7	2250	2190	2330	18.7	10.2	7.5
	14	2320	2230	2450	24.7	14.3	13.6
	21	2330	2380	2300	25.0	20.8	14.8
	28	2280	2180	2400	27.4	22.2	15.6
50	7	2280	2380	2250	14.8	9.7	5.4
	14	2300	2400	2280	24.1	12.4	9.3
	21	2230	2300	2250	24.8	17.6	10.6
	28	2280	2330	2300	25.3	19.7	13.4
60	7	2300	2420	2280	13.8	8.2	5.7
	14	2250	2350	2150	19.7	9.3	7.8
	21	2230	2230	2300	22.1	14.3	8.9
	28	2350	2320	2250	23.8	17.6	11.7
70	7	2280	2300	2320	12.3	7.6	4.3
	14	2300	2320	2300	18.4	8.6	7.4
	21	2250	2280	2250	21.9	11.4	7.3
	28	2300	2280	2230	22.5	12.8	9.6
80	7	2280	2250	2220	11.4	6.2	3.7
	14	2330	2300	2230	16.0	7.9	5.9
	21	2280	2230	2180	20.8	9.1	7.0
	28	2280	2190	2210	21.7	10.2	7.7
90	7	2300	2260	2250	9.8	4.8	3.1
	14	2300	2320	2200	14.2	5.6	5.1
	21	2260	2200	2200	18.9	8.0	6.5
	28	2260	2120	2200	19.9	8.7	7.2
100	7	2320	2000	2230	9.3	3.7	2.4
	14	2300	2210	2100	12.3	4.0	4.0
	21	2180	2100	2050	14.3	4.8	5.2
	28	2180	2040	2100	15.9	6.8	6.0

*The water-cement ratios for the mix proportion of 2:3:6,1:2:4 and 1:3:6 are respectively 0.55, 0.65 and 0.75.

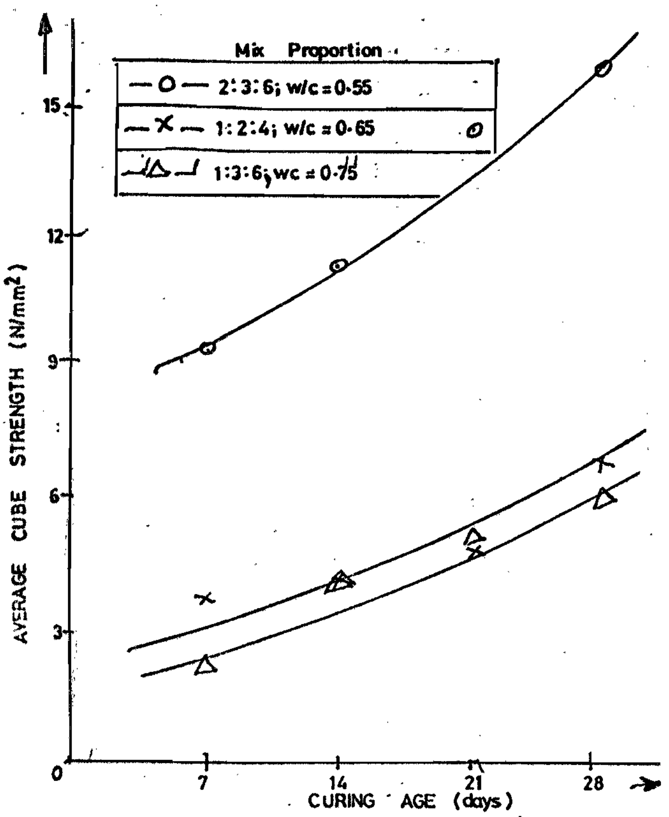

Fig-3: Compressive strength-age characteristics of different mix proportions for palm-kernel shell concrete (100% palm-kernel shell aggregate)

28 days strength was developed in 7 days in all the cubes tested. The early strength development is not unconnected with the fine grains of the palm-kernel shell that falls nearly within the same bracket as the river sand in addition to the high uniformity coefficient of palm-kernel shell.

Whereas, general decrease in compressive strength from 0 to 100% content of palm-kernel shell replacement is consistently around 3% for the various mixes, this near constant variation in strength is not observed for all the mixes from 0 to 50% palm-kernel shell content. The highest strength was exhibited by the mix proportion 2:3:6 by weight with water/cement ratio of 0.55 followed by that of 1:2:4 with water/cement ratio of 0.65.
This is expected as in normal river sand concrete, possibly due to higher cement content in the mix (Sadiq et al, 1999).
The compressive strength at 28 days for all the mixes 2:3:6 ; 1:2:4 ; and 1:3:6 using100% palm-kernel shell was less than 20N/mm^2 implying that none of the mixes is suitable for use in load-bearing structural elements. However, in mixes 2:3:6, and 1:2:4 at 28 days, using 60% sand and 40% palm-kernel shell, the compressive strength values were 27.4N/mm^2 and 22.2N/mm^2 respectively. This indicates that partial replacement of palm-kernel shell with sand in the ratio mentioned above is suitable for concrete for load-bearing structural elements.

The investigation gave values of 3.78N/mm^2 and 1.96N/mm^2 respectively for concrete beam from normal sand and palm-kernel shell for mix of 2:3:6. In the case mix of 1:2:4, the values are 2.2N/mm^2 and 1.48N/mm^2 for normal sand and palm-kernel shell concrete beams respectively while for mix 1:3:6, the flexural strength values are 2.02N/mm^2 and 0.37N/mm^2 for normal sand and palm-kernel shell concrete beams respectively. The difference in values of the strength of concrete beams cast with two aggregates is possibly due to lack of adequate bond strength between cement and palm-kernel shell on one hand and presence of effective bond strength between cement and sand on the other hand.

Figure 4 reveals that the flexural strength of plain concrete beams do depend much on the percent content of palm-kernel shell as well as on the mix proportion. The mix proportion of 2:3:6 exhibited the highest flexural strength of 1.96N/mm^2 followed by 1:2:4 mix of 1.48N/mm^2 for one hundred percent palm-kernel shell content. This is also due to higher cement content in the mix.

Flexural Strength

Table 3 gives the strength variation of flexural strength in concrete with percent palm-kernel shell content while figure 4 shows the effect of mix proportion on flexural strength of plain concrete beams with different percentages of palm-kernel shell content.
Analysis of the table shows a significant difference in the flexural strength of beams produced from normal sand and those produced from palm-kernel shell.

Table 3: Variation of Strength in Concrete with % Palm-kernel Shell Content

%Palm-kernel content	Mix proportion*	Flexural strength of plain p/k shell concrete (N/mm^2)	Position of fracture to nearest support (mm)
0	2:3:6	3.78	179
	1:2:4	2.20	193
	1:3:6	2.02	179
10	2:3:6	3.64	163
	1:2:4	2.0	197
	1:3:6	1.90	179
20	2:3:6	3.60	162
	1:2:4	1.64	175
	1:3:6	1.56	191
30	2:3:6	3.52	171
	1:2:4	1.64	182
	1:3:6	1.50	159
40	2:3:6	3.20	181
	1:2:4	1.62	159
	1:3:6	1.38	138
50	2:3:6	2.78	125
	1:2:4	1.56.	149
	1:3:6	0.64	107
60	2:3:6	2.20	138
	1:2:4	1.60	197
	1:3:6	0.52	112
70	2:3:6	2.18	136
	1:2:4	1.58	197
	1:3:6	0.53	119
80	2:3:6	2.0	141
	1:2:4	1.60	161
	1:3:6	0.46	125
90	2:3:6	1.96	135
	1:2:4	1.56	151
	1:3:6	0.38	114
100	2:3:6	1.96	149
	1:2:4	1.48	148
	1:3:6	0.37	107

*The w/c ratios for the mix proportions of 2:3:6, 1:2:4 and 1:3:6 are respectively 0.55, 0.65 and 0.75.
The position of fracture for different mix proportions and palm-kernel shell contents is at the middle third of the beam where it is pure flexure.

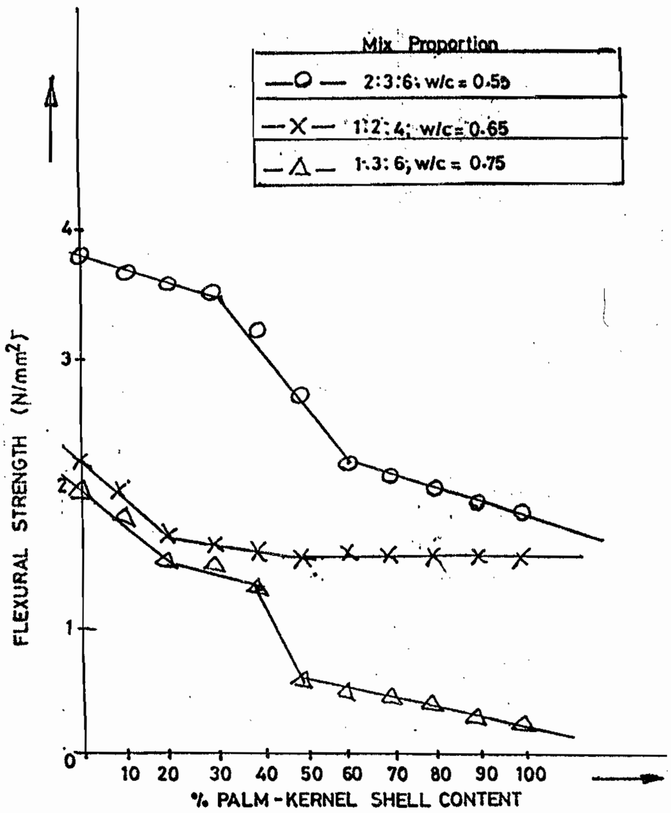

Fig. 4: Flexural strength of plain concrete with varying % content of palm-kernel shell.

CONCLUSSIONS AND RECOMMENDATIONS

Conclusions

The results of the experimental investigation carried out showed the following:

1. With average concrete density of about 2400Kg/m^3 (Table 2), moisture content of 10.5%, and specific gravity of 1.33 (measured), palm-kernel shell can be comparable with lightweight aggregate for the production of lightweight concrete.

2. There exists a consistent pattern of strength-age curves for concrete with normal sand and palm-kernel shell content, though palm-kernel shell concrete exhibited lower strength at 28 days compared to the corresponding river sand concrete. There was early strength development; about 60% of 28 days strength was observed at 7 days in nearly all mixes.

3. For a given mix proportion, the compressive strength decreases gradually with increase in palm-kernel shell content. However, in all the three mixes with 100% palm-kernel shell content, and all ages, mix 2:3:6 gives the highest compressive strength (Table2).

4. The flexural strength of plain concrete beams with varying palm-kernel shell content depends on the percentage content of the palm-kernel shell and also on the mix proportion. The mix proportion of 2:3:6 with water/cement ratio of 0.55 showed the highest value.

5. In both compression and flexure, partial substitution of 60% normal sand and 40% palm-kernel shell content produced concrete with adequate strength values.

With the above information, it can therefore be concluded that the presence of palm-kernel shell in concrete reduces the strength characteristics compared to normal river sand. Palm-kernel shell can therefore be considered as a total or partial substitute for river sand in concrete for non-load-bearing structural elements.

RECOMMENDATIONS

This investigation was carried out on partial replacement of fine aggregate with palm-kernel shell on short-term strength characteristic and normal exposure condition. It is recommended that future work should concentrate on long-term resistance and durability of concrete with palm-kernel shell. The impact tests should also be considered for concrete with palm-kernel shell content.

A concentration on the very common mixes of 1:3:6 and 1:2:4, used more predominantly, with different water/cement ratios is necessary for further investigation in order to give guidance on design mixes.

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