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# Experimental Study on Palm Kernel Shells as Coarse Aggregates in Concrete

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**Abstract**— This paper reports on experimental investigations on the effects of replacing crushed granite in concrete with palm kernel shells on the strength, density and workability of concrete. Two control mixes of ratios 1:2: 4 were batched by volume and by weight. Palm kernel shells were used to replace the crushed granite aggregate by volume and by weight respectively. The percentage replacement varied from 0% to 100% at intervals of 25%.The compaction factor test was used to assess the workability of the fresh concrete .The compressive strengths and densities of cured concrete cubes of sizes, 150mm×150mm×150mm were evaluated at 7days, 14days, 21days and 28days. Increase in the percentage replacement of granite lowered compressive strength, density and workability. Density on the average decreased at a rate of 7kgm$^{-3}$ and 11kgm$^{-3}$ per unit percentage increase in replacement for volume-batched concrete and weight-batched concrete respectively while compressive strength decreased at a rate of 0.11Nmm$^{-2}$ and 0.22Nmm$^{-2}$ per unit percentage increase in palm kernel shell content for volume-hatched concrete and weight-batched concrete respectively. There exists the possibility of replacing coarse aggregates with palm kernel shells in the production of structural concrete. The study identified possible cost reduction in replacing granite with palm kernel shells and recommended codification of the use of palm kernel shells as aggregates in concrete.

**Index Terms**— coarse aggregate, compressive strength, concrete, density, palm kernel shells, workability,

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## 1.0 INTRODUCTION

Concrete is the world's most consumed man made-material (Naik, 2008). Its great versatility and relative economy in filling wide range of needs has made it a competitive building material (Sashidar and Rao, 2010). Concrete production is not only a valuable source of societal development, but it is also a significant source of employment. (Naik, 2008)

Production of concrete relies to a large extent on the availability of cement, sand and coarse aggregates such as granite, the costs of which have risen astronomically over the past few years. Despite the rising cost of production, the demand for concrete is increasing. The negative consequences of the increasing demand for concrete include depletion of aggregate deposits; environmental degradation and ecological imbalance (Short & Kinniburg, 1978). The possibility of complete depletion of aggregates resources in the near future can therefore not be over emphasized.

Rising construction costs and the need to reduce environmental stresses to make construction sustainable, has necessitated research into the use of alternative materials, especially locally available ones which can replace conventional ones used in concrete production. The use of such replacement materials should not only contribute to construction cost reduction and drive infrastructural development but also contribute to reduce stress on the environment and make engineering construction sustainable to help transform the building and construction sectors of national economies and contribute towards the realization of national and global poverty reduction strategies. Such materials should be cheap and readily available. The use of cheaper building materials without loss of performance is very crucial to the growth of developing countries (Zemke & Woods, 2009).

Historically, agricultural and industrial wastes have created waste management and pollution problems. However the use of agricultural and industrial wastes to complement other traditional materials in construction provides both practical and economical advantages. The wastes generally have no commercial value and being locally available transportation cost is minimal (Chandra & Berntsson, 2002).

Agricultural wastes have advantages over conventional materials in low cost construction (Abdullah , 1997).The use of waste materials in construction contribute to conservation of natural resources and the protection of the enviroment. (Ramezanianpour, Mahdikhani & Ahmadibeni, 2009). Nimityongskul and Daladar (1995) investigated the use of coconut husk ash, corn cob ash and peanut shell ash as cement replacement in concrete production. Slim and Wakefield (1991) investigated the use of water works sludge in the manufacture of clay bricks.

The palm oil industry produces wastes such as palm kernel shells, palm oil fibres which are usually dumped in the open thereby impacting the environment negatively without any economic benefits. Palm kernel shells (PKS) are hard, carbonaceous, organic by- products of the processing of the palm oil fruit. PKS consists of small size particles, medium size particles and large size particles in the range 0-5mm, 5-10mm and 10-15mm (Alengaram, Mahmud, Jumaat & Shiraz, 2010). The shells have no commercial value, but create disposal and waste management problems. In Ghana, palm kernel shells are generally not used in construction. They are used as fuel by local blacksmiths and as fill material or as palliatives.

Ndoke (2006) investigated the suitability of palm kernel shells as partial replacement for coarse aggregates in asphal-

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tic concrete. Olutoge (2010) investigated the suitability of sawdust and palm kernel shells as replacement for fine and coarse aggregate in the production of reinforced concrete slabs. He concluded that 25% sawdust and palm kernel substitution reduced the cost of concrete production by 7.45%. He also indicated the possibility of partially replacing sand and granite with sawdust and palm kernel shell in the production of lightweight concrete slabs. Olanipekun (2006) compared concrete made with coconut shells and palm kernel shells as replacement for coarse aggregates and concluded that coconut shells performed better than palm kernel shells as replacement for conventional aggregates in the of concrete.

As part of efforts to make efficient use of locally available materials, this study was conducted to investigate and compare the influences of weight replacement and volume replacement of conventional aggregates by palm kernel shells on the workability, density and compressive strength of concrete as well as to assess the suitability of palm kernel shell concrete as a structural material.

## 2.0 MATERIALS AND METHODS

Crushed granite used for the study was of size 20mm. It was obtained from Sarobi quarry near Elmina in the Central Region of Ghana. The palm kernel shells used were sourced from the palm kernel oil production site at Abura in Cape Coast. The shells were flushed with hot water to remove dust and other impurities that could be detrimental to concrete. They were sun-dried and packed in plastic sheets to prevent contact with water.

Natural river sand was used in producing the concrete. Ordinary Portland cement manufactured by Ghana Cement Factory at Takoradi in the Western Region of Ghana, and conforming to BS 12(1996) was used in the concrete production.

Water supplied by Ghana Water Company was used in mixing the materials. The water looked clean and was free from any visible impurities. It conformed to the requirements of BS 1348 (1980).

The study utilized two control mixes ratio of 1:2:4, batched by volume and 1:2:4, batched by weight. A water cement ratio of 0.6 was used in both mixes. The percentage replacements of the aggregates by PKS were 0%, 25%, 50%, 75% and 100% by volume and by weight respectively.

The casting was done in cast iron moulds measuring 150mm × 150mm × 150mm internally. The specimens were made in accordance with BS 1881(1996). A total of one hundred and twenty (120) cubes were cast: twelve (12) for each percentage replacement for each mix. After casting, the moulds were covered with plastic sheets to prevent loss of water. The specimens were removed from the mould after twenty four hours and immersed in a curing tank to hydrate for strength gain for crushing at 7days, 14days, 21days and 28 days. Long period of moist curing reduces the incidence of cracking (Kong and Evans, 1994).

The compaction factor apparatus was used to assess workability of the fresh concrete. The concrete cubes were crushed using Matest Digital Compression Machine (Fig. 1) which automatically evaluates both the compression load and the compressive stresses at failure and displays the results on an LCD screen. The cubes were removed from the curing tank and left in the open air for about two hours before crushing. The density of each specimen was determined before crushing. All tests were conducted at the Materials Laboratory of the Department of Civil Engineering of the Cape Coast Polytechnic.

Fig 1. Matest Digital Compression Machine

## 3.0 RESULTS AND DISCUSSION

### 3.1 Workability

The results obtained from the compaction factor test are presented in Table 1. It can be seen that, for both mixes workability of reduces as the of palm kernel shell content increases.

Table 1. Results of workability test (Compacting Factor)

| Replacement (%) | 0 | 25 | 50 | 75 | 100 |
|---|---|---|---|---|---|
| Volume batch | 0.89 | 0.88 | 0.87 | 0.85 | 0.83 |
| Weight batch | 0.91 | 0.82 | 0.54 | 0.34 | 0.20 |

The workability of both mixes decreases with increase in the percentage replacement of granite by PKS. This is due to the increase the specific surface as a result of the increase in the quantity of PKS, thus requiring more water to make the specimens workable. The workability of the volume-batched concrete produced by volume replacement of granite by palm kernel shells is higher than that produced by weight replacement. The rate at which workability reduces per unit percentage increase in PKS is lower for the volume-batched concrete than for weight-batched concrete. Since granite is denser than palm kernel shells, replacement by an equal mass of palm kernel shells leads to a larger increase in volume than replacement by an equal volume of granite. Increase in the quantity of shells increase the specific surface area, thereby more water would be required. However, since the water cement ratio remains the same, the workability of the mix reduces.

### 3.2 Density

The densities of volume-batched PKSC and weight-batched PKSC concrete are presented in Table 2 and Table 3 respectively.

Table 2. Density of PKSC (volume-batched) ($kgm^{-3}$)

| Age at testing(days) | Palm kernel shell replacement (%) | | | | |
|---|---|---|---|---|---|
| | 0 | 25 | 50 | 75 | 100 |
| 7days | 2397 | 2212 | 2022 | 1905 | 1673 |
| 14days | 2401 | 2218 | 2039 | 1923 | 1690 |
| 21days | 2407 | 2226 | 2058 | 1930 | 1698 |
| 28days | 2412 | 2241 | 2063 | 1948 | 1710 |

The variation of density of concrete with palm kernel shell content is shown in Fig. 2. It is seen that in both mixes, the density of concrete reduces as percentage content of palm kernel shells increases. The densities of both types of mix increase with age. The minimum and maximum densities occur at complete replacement (100% PKS) and at no replacement (100%granite) respectively.

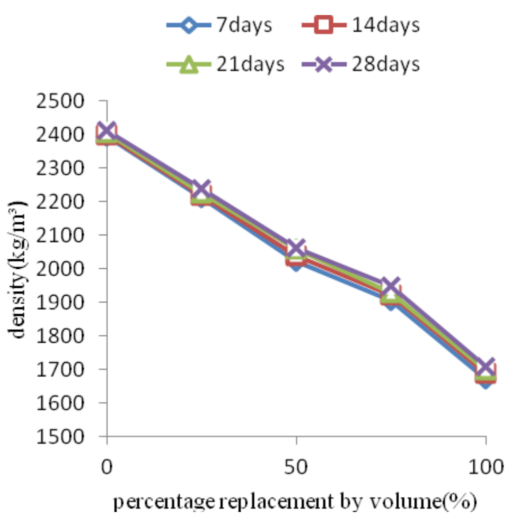


Fig 2 Variation of density with palm kernel shell content (1:2:4 by volume)

The minimum 28-day densities of weight-batched PKSC and volume batched PKSC are 1292kgm-3 and 1710 kgm-3 respectively. For the volume replaced concrete, PKSC with 50% replacement of granite can be regarded as normal weight (density>2000kgm-3), while for weight-batched concrete, 25% replacement of granite can be regarded as normal weight concrete. It is seen that the rate at which densities decrease with increase in the percentage replacement is higher for the weight-batched PKSC than for volume-batched concrete

Table 3. Density of PKSC (weight-batched) ($kgm^{-3}$)

| Age at testing(days) | Palm kernel shell replacement (%) | | | | |
|---|---|---|---|---|---|
| | 0 | 25 | 50 | 75 | 100 |
| 7days | 2328 | 2055 | 1680 | 1366 | 1181 |
| 14days | 2370 | 2109 | 1713 | 1392 | 1210 |
| 21days | 2378 | 2122 | 1786 | 1465 | 1239 |
| 28days | 2392 | 2177 | 1835 | 1519 | 1292 |

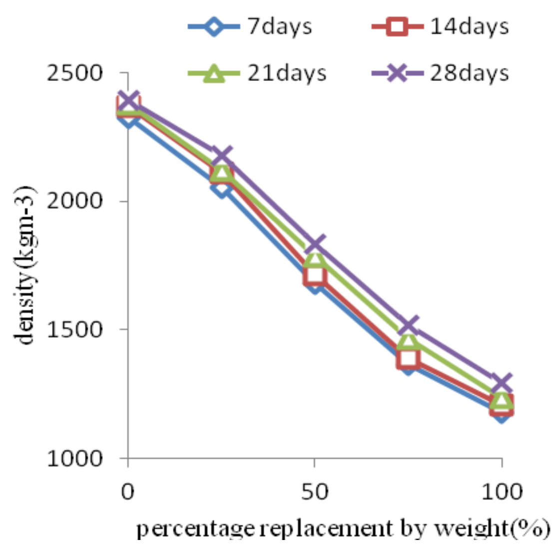


Fig 3 Variation of density with palm kernel shell content (1:2:4 by weight)

This is attributed to the larger increase in the quantity of palm kernel shells in weight-batched PKSC than in volume-batched PKSC. Replacement of granite by equal weight of PKS leads to the introduction of more palm kernel shells in the mix since granite is heavier than palm kernel shell. This leads to an increase in volume without increase in weight which reduces the density. The density of volume-batched concrete on the average reduces by about 7$kgm^{-3}$ per unit percentage increase in replacement whereas density of weight-batched concrete on the average reduces by about 11$kgm^{-3}$per unit percentage increase in palm kernel shells.

### 3.3 Compressive Strength

Data obtained from the crushing test on volume-batched concrete are presented in Table 4.

Table 4 Compressive strengths of volume-batched PKSC ($Nmm^{-2}$)

| Age at testing(days) | Palm kernel shell replacement (%) | | | | |
|---|---|---|---|---|---|
| | 0 | 25 | 50 | 75 | 100 |
| 7days | 15.00 | 12.11 | 9.34 | 8.71 | 3.10 |
| 14days | 18.69 | 14.52 | 13.02 | 12.70 | 6.88 |
| 21days | 19.65 | 15.30 | 14.42 | 14.31 | 7.87 |
| 28days | 21.80 | 16.64 | 15.00 | 15.18 | 10.37 |

Table 5 Compressive strengths of weight-batched PKSC ($Nmm^{-2}$)

| Age at testing(days) | Palm kernel shell replacement (%) | | | | |
|---|---|---|---|---|---|
| | 0 | 25 | 50 | 75 | 100 |
| 7 | 16.25 | 11.61 | 4.67 | 1.56 | 0.93 |
| 14 | 18.84 | 13.24 | 6.16 | 1.87 | 1.00 |
| 21 | 20.91 | 14.82 | 7.21 | 2.19 | 1.34 |
| 28 | 24.02 | 16.33 | 7.89 | 2.82 | 1.84 |

The compressive strengths of weight-batched concrete at various palm kernel shell content are shown in Table 5.The effects of replacement of granite with palm kernel shells on compressive strengths of the specimens are shown in Fig. 4 and Fig. 5 respectively. It is seen that the compressive strength decreases the as palm kernel shells content increases. The compressive strength is maximum at 0% replacement by PKS and minimum at 100% replacement

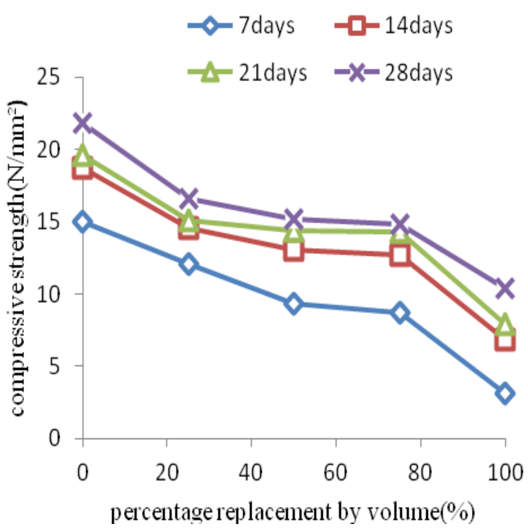


Fig 4 Variation of compressive strength with palm kernel shell content

As palm kernel shell content increases, the specific area increases, thus requiring more cement paste to bond effectively with the shells. Since the cement content remains the same, the bonding is therefore inadequate. Strength depends to a large extent on good bonding between the cement paste and the aggregates. The compressive strength reduces as a consequence of the increase in percentage replacement of granite.

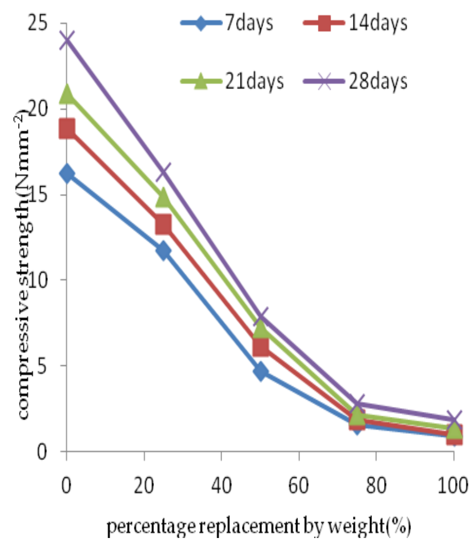


Fig 5 Variation of compressive strength with palm kernel shell content

The 28-day compressive strength of volume-batched concrete on the average, reduces by about 0.11 Nmm-2 per unit percentage increase in replacement by palm kernel shells, whereas the 28-day compressive strength of weight-batched concrete on the average reduces by about 0.22 Nmm-2 per unit percentage increase in replacement by palm kernel shells. The 28-day strength of volume-batched concrete was in the range 5-19.5 Nmm-2, satisfying the criteria for classification as lightweight concrete (Chandra and Berntsson, 2002). For weight-batched PKSC, the 28-day strength represented by 64% replacement by PKS satisfies the criteria for lightweight aggregate. For volume replaced PKSC, 50% replacement attained a compressive strength of 15.18 Nmm-2, while for weight-batched PKSC, 29% replacement attained a compressive strength of 15$Nmm^{-2}$.
Table 6 shows the recommended grades of concrete according to BS 8110(1997).

Table 6 Recommended grades of concrete (BS 8110, 1997)

| Grade | Characteristic strength | Concrete class |
|---|---|---|
| 7<br>10 | 7.0<br>10.0 | Plain concrete |

| | | |
|---|---|---|
| 15 | 15.0 | Reinforced concrete with Lightweight aggregate |
| 20<br>25 | 20.0<br>25.0 | Reinforced concrete with dense aggregate |
| 30 | 30.0 | Concrete with post tensioned tendons |
| 45<br>50<br>60 | 40.0<br>50.0<br>60.0 | Concrete with pre tensioned tendons |

Therefore, replacements of 50% or less in volume batched-concrete and 29% or less can be used as reinforced concrete with lightweight applications (See Table 6).
Similarly, 8% and 13% replacement of crushed granite by PKS in volume batched-concrete and weight-batched concrete attained a 28-day compressive strength of 20Nmm-2; equivalent to grade 20 concrete (Table 6). They can therefore be potentially used in reinforced concrete works.

## 3.4 Cost Implications

The results in 3.3 have indicated that it is possible to use palm kernel shells concrete to replace granite in concrete. Since palm kernel shells are acquired at virtually no cost, about 8%of the cost of granite in volume batched aggregate and 13% of the cost of granite in volume batched concrete can be saved. Therefore, cost of producing concrete would be reduced as granite is replaced by palm kernel shells.

## 4.0 CONCLUSION

At the end of the study the following conclusions are made:

- There exists a high potential for the use of palm kernel shells as aggregates in the manufacture of lightly reinforced concrete.
- PKSC batched by volume replacement or weight replacement of coarse aggregate with palm kernel shells show similar trends in the variation of density, workability and strength with increase in percentage replacement
- Loss of strength ,workability and density per increase in percentage replacement by PKS is higher for weight-batched concrete than for volume batched concrete
- There are potential cost reductions in concrete production using palm kernel shells as partial replacement for crushed granite
- Based on the results obtained, replacement of 8% crushed granite by palm kernels shell in volume-batched concrete can be used in reinforced concrete construction whereas replacement of 13% if crushed granite in weight batched concrete can be used in reinforced concrete construction.
- Palm kernel shell concrete batched by volume performed better than that batched by weight.

## 5.0 RECOMMENDATIONS

- Though the results indicated the possible use of palm kernel shell as a structural material, it is recommended that its long-term behaviour should be investigated to evaluate this possibility.
- Plasticizers should be used in works involving palm kernel shell concrete.
- Volume batching should be used in palm kernel shell concrete construction
- Further research should be conducted to codify the use of PKSC as structural material.

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