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Comparative Study of the Physical Properties of Palm Kernel Shells Concrete and Normal Weight Concrete in Ghana

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ABSTRACT

Concrete is one of the most widely used construction materials in the world. To ensure sustainability and a reduction in the cost of concrete, the use of renewable agricultural waste materials as aggregates becomes desirable. This paper presents results of a comparative study of the physical and compressive strength of palm kernel shell concrete (PKSC) and normal weight concrete (NWC) using Portland-limestone cement (class 32.5R) and Ordinary Portland Cement (OPC) herein called Ghacem Extra Cement(class 42.5N). Palm kernel shells were used as lightweight coarse aggregate in PKSC and granite was used as aggregates for the normal concrete. The study was conducted in accordance with the British Standards (BS 812, 1990; BS 1881, 1996). Two mixes of ratios 1:1.3:0.7 and 1:1.7:2.5 by weight were used in the study. The values obtained for water absorption, aggregate impact, aggregate crushing, specific gravity and Los Angeles abrasion, satisfy the minimum requirements of aggregates for structural concrete as specified in BS 882, 1992. The density of the PKSC was about 22% lower than that of the normal weight concrete for both cement types. Compressive strengths of both PKSC and normal weight concretes with Portland-limestone cement and Ghacem Extra cement evaluated at 7, 14 and 28-days showed that Ghacem Extra cement produced concretes of higher compressive strengths than Portland-limestone cement for PKSC and normal weight concrete. In general, the compressive strength of PKSC using Ghacem Extra cement compare well with those obtained from other materials used for structural lightweight concretes.

Keywords: *Agricultural waste, Lightweight Aggregates, Palm Kernel Shells, Density, Compressive Strength.*

Introduction

Concrete has unlimited opportunities for innovative applications, design and construction techniques. Its versatility and relative economy in meeting wide range of needs has made it a very competitive building material. Both natural and artificial aggregates are used in the production of concrete in the construction industry. Fine and coarse aggregates which generally occupy 60% to 75% of concrete volume strongly influence concrete's freshly mixed and hardened properties as well as its mix proportions and economy (Neville and Brooks, 2008; Alexander and Mindess, 2005; Quiroga & Fowler, 2004; Komatka *et al*., 2003; Galloway, 1994). In Ghana, natural sand and crushed gravels have been used for many years as aggregates for concrete production due to their availability across the country. However, the high demand for normal weight concrete for construction continues to drastically reduce the natural stone deposits and consequently damage the environment. The introduction of artificial and natural lightweight aggregates (LWA) to replace conventional aggregates for the production of concrete in many developed countries, has brought immense benefits in the development of infrastructure, especially, high rise structures using lightweight concrete (Mahmud *et al*., 2009).

The increasing cost of construction materials, and the environmental degradation caused by the high exploitation of aggregates for concrete has necessitated the search for affordable and environmentally friendly construction materials in Ghana. Adom-Asamoah and Russell (2010) investigated the use of phyllite aggregates (aggregates produced as a by-product of underground mining activities of AngloGold Ashanti in Ghana) in concrete, and concluded that phyllite aggregates produced concrete with properties similar to that of normal weight concrete. The use of agricultural wastes as aggregate or cement replacement material in concrete also has both engineering potential and economic advantage. Earlier investigations showed that PKS can be used as coarse aggregates in concrete (Mannan and Ganapathy, 2004; Teo *et al.,* 2007). Bernasco (2004) investigated the use of palm kernel shells (PKS) as chippings in terrazzo flooring and concluded that it could be used alone in low traffic areas or replace about 30% volume of marble chippings in high traffic areas. Bergert (2000), however, reported that PKS could be mixed with mud and formed into blocks for the construction of traditional homes. In a separate study, Alengaram *et al.*, (2008) reported on the effect of cementitious materials, fine and coarse aggregates content on the workability and compressive strength of palm kernel shell concrete. The authors reported of about 10% to 15% increase in strength for mixes containing silica fume. It was further reported that the silica fume plays a major role in early strength development of PKS concrete. That notwithstanding, the use of PKS as construction material is not common in the Ghanaian construction industry. This may be attributed to the non-availability of technical information to support their use or the low resource base of palm kernel shells in the past compared with the conventional sand and gravels aggregates (Ndoke, 2006).

This paper presents results of a study to compare key physical properties of palm kernel shells concrete (PKSC) and normal weight concrete Portland-limestone cement (class 32.5R) and Ordinary Portland Cement (OPC) herein called Ghacem Extra Cement (class 42.5N).

Materials and Methods

Materials

The cement types used in this study were Portland-limestone cement and Ordinary Portland Cement (OPC) herein called Ghacem Extra Cement conforming to BS EN 197-1 (2000). The Portland-limestone cement and Ghacem Extra cement conforms to strength classes 32.5R and 42.5N respectively as specified in BS EN 197-1 (2000). The fine aggregate used in the study was local mining sand, and the coarse aggregates were crushed palm kernel shells (for the PKSC) and granite (for the normal weight concrete). The local mining sand had maximum aggregates size of 4.75 mm, specific gravity of 2.66, moisture content of 4% and a fineness modulus of 2.71. Clean water (free of deleterious materials) supplied by the Ghana Water Company, conforming to BS 1348 (1980), was used for mixing the materials.The properties of the coarse aggregates used are presented in Table 1. The PKS used were obtained from a palm kernel oil production site at Ayigya in the Ashanti region.

The shells were flushed with hot water to remove dust and other impurities which could be detrimental to the concrete. They were dried indoors under laboratory conditions for four months. The PKS used were in various shapes, such as flaky, elongated, roughly parabolic, and other irregular shapes.The aggregates were oven dried and the physical properties were determined in accordance with BS 812 (1990). Due to the high water absorption capacity of the PKS aggregates, they were pre-soaked in water for 24 hours and subsequently air dried.

Experimental procedure

The physical properties studied were aggregate impact value (AIV), water absorption, relative density, aggregate crushing value (ACV), elongation index (EI) and flakiness index (FI). The PKS and granite aggregates used in the study were sampled from portions passing 14mm sieve size and retained on the 10mm sieve size. The flakiness of both PKS and granite were determined by separating the flaky particles and expressing their masses as a percentage of the mass of the sample tested (BS 812 part 105, 1990). The water absorption of the PKS was determined in accordance with the recommendations for testing aggregates in BS 812 (1990) by measuring the decrease in mass of a saturated and surface dry sample after oven drying for 24 hours. The water absorption was determined as the ratio of the decrease in mass to the total mass of the sample expressed as a percentage. Relative density was determined from the ratio of the density of the aggregates to the density of water in accordance with the American Standard for Testing Materials, ASTM C127-07 (2007). The AIV of the PKS and granite aggregates were determined in accordance with BS 812 (1990) by measuring the degree to which impacted samples break depending on the impact resistance of the material. The ACV of the PKS and granite aggregates were determined in accordance with provisions in BS 812 (1990). The AAV for the PKS and granite aggregates were determined in accordance with BS 812 (1990). Shetty (2005) reported that mix design methods that apply to normal weight concrete are generally difficult to use with lightweight aggregate concrete. This study therefore used trial mixes as suggested by Sin (2007) in order to achieve a good mix design for the lightweight concrete. The ratio

Cement : Sand : PKS by weight was equivalent to 1:1.3:0.7, with the fine and coarse aggregates occupying about 68 percent of the total weight of the PKS concrete content.The mix comprised 550 Kg/m^3 cement, 715Kg/m^3 granite fines, and 385Kg/m^3 PKS, with a free water/cement ratio of 0.38 for the PKSC. The cement content used in this study was within the range allowed for lightweight concrete (Mindess *et al*., 2003). For comparison purposes, a normal weight concrete (control concrete) was prepared from the crushed granite aggregates.The control mix was in the ratio of 1:1.7:2.5 with water/cement ratio of 0.45 by weight. The test specimens were made in cast iron moulds measuring 150mm×150mm×150mm in accordance with BS 1881-116(1996). A total of sixty cubes were cast, fifteen (15) cubes for each mix design for each cement type. Concrete placed in the moulds were compacted using an electrically operated vibrator to reduce the amount of voids. Each mix was identified with a unique identity (ID). In the mix ID, PKSC identifies palm kernel shells concrete, NWC identifies normal weight concrete, and the last letter 'A' or 'B' identifies the type of cement used. Letter 'A' denotes Portland-limestone cement and 'B' denotes Ghacem Extra cement. After casting, the specimens were removed from the mould after 24 hours and totally immersed in water in a curing tank to hydrate for strength gain. Long period of moist curing reduces the incidence of cracking (Kong and Evans, 1994). The cured test specimens were left in the open air for about 30 minutes before crushing at 7days, 14days and 28 days. The compressive strength of the concrete cubes was tested at the Civil Engineering Laboratory of the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, using a Universal Compression Testing Machine of maximum capacity 500 KN. The weight of each test specimen was determined 30 minutes before the crushing test and density was calculated as the ratio of the weight to the volume of each specimen.

Results and Discussion

Physical and Mechanical Properties

- *Aggregate Shape and Texture:-* BS 812: part 105 (1997) classifies aggregates as flaky when they have a thickness (smallest dimension) of less than 0.6 of their mean sieve sizes, while aggregate particles with a length (greatest dimension) of more than 1.8 of their mean sieve size are classified as elongated. The test results for the physical properties presented in Table 1 show that the palm kernel shells (PKS) and the granites have flakiness index of 63% and 31% respectively. The elongation index obtained for PKS and granite are 17% and 22% respectively. BS 882 (1992) specifies an upper limit of 50% for uncrushed gravels and 40% for crushed gravel. This means that the PKS which is flakier than the granite exceeds the upper limit specified in BS 882 (1992). The shape of aggregate particles influences water absorption, paste demand, placement characteristics such as workability, strength, void content, packing density and cost (Rached *et al*., 2009). According to Legg (1998) and Shilstone (1990), flaky and elongated particles tend to produce harsh mixtures, and affect mobility of mixtures. The results indicate that water absorption and paste demand for the PKS concrete will be higher than those for the granite concrete, and this may eventually result in concrete of a lower strength.

- *Grading/Particle Size Distribution:*-The gradation of an aggregate is defined as the frequency of distribution of the particle sizes of a particular aggregate (Lamond & Pielert, 2006; Rached *et al*., 2009). Figures 1 to 3 show particle size distribution of the palm kernel shells, granite and fine aggregates respectively.The grading of each aggregate type is observed to be within the upper and lower limit requirements of BS 882 (1992). The results imply that a workable concrete with less void content can be produced from the aggregates, resulting in concrete of high quality. Grading significantly affects some characteristics of concrete like voids content, workability, segregation and durability of concrete (Ozol, 1978) Grading determines the paste requirement for a workable concrete since the amount of void required needs to be filled by the same amount of cement paste in a concrete mixture. In general, studies have shown that a well-graded aggregate greatly contributes to the overall quality of concrete than gap-graded mixtures (Chandra & Berntsson, 2002; Glavind *et al*., 1993), and desirable for efficient use of the paste. Uniformly distributed mixtures lead to higher packing, resulting in concrete with higher density, less permeability, decreased cost of production, easy placement and enhanced overall quality of the concrete (Golterman *et al.*, 1997; Glavind *et al.*, 1993), and improved abrasion resistance (Mehta & Monteiro, 1993).

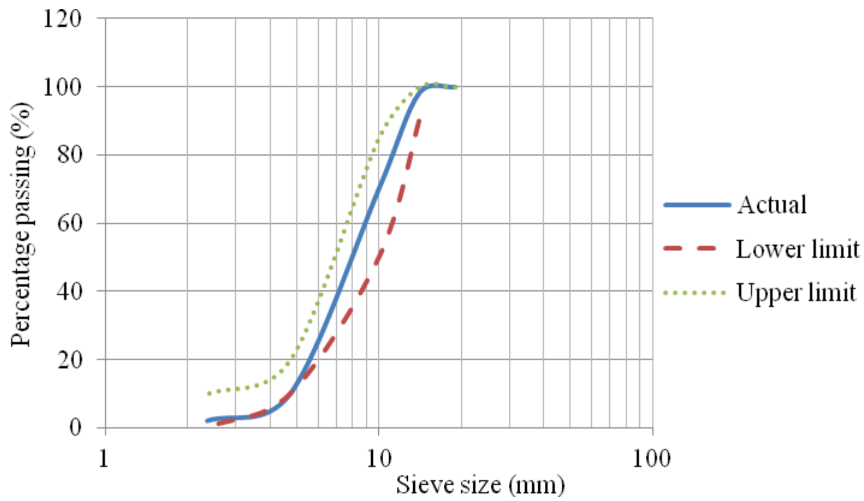

Fig. 1 Particle Size Distribution of PKS Aggregate

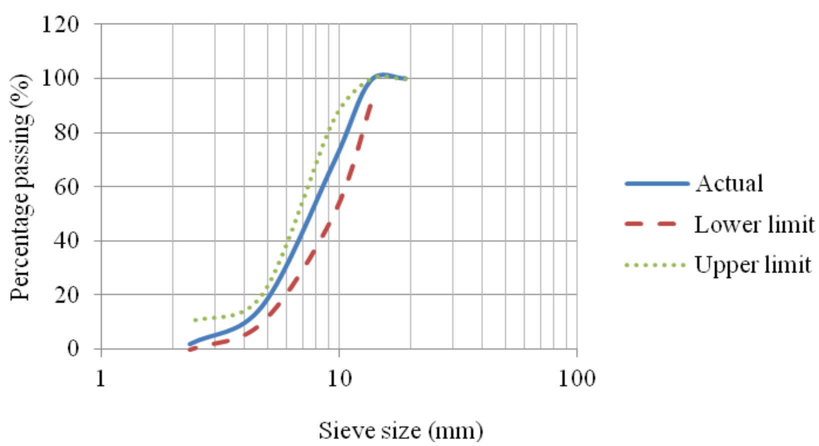

Fig. 2 Particle Size Distribution of Granite Aggregate

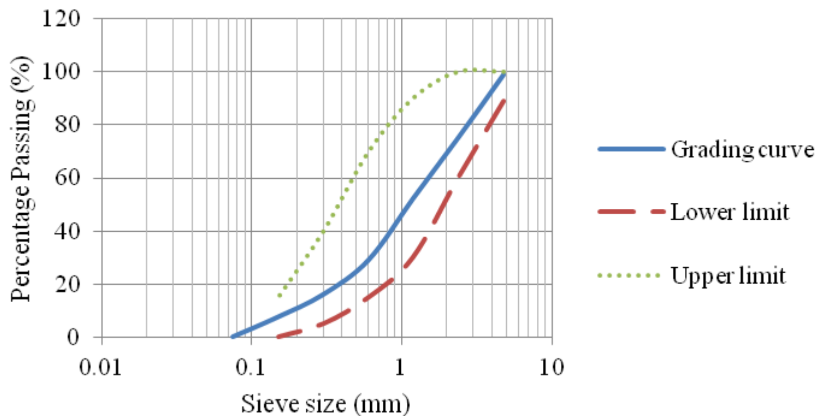

Fig.3 Particle Size Distribution of Fine Aggregate

- *Water Absorption and Porosity:-* Absorption relates to the particle's ability to take in a liquid. The presence of pores in aggregates makes them absorptive. Porosity is a ratio of the volume of the pores to the total volume of the particle. Lightweight aggregates (LWA) with open surface texture and a large interconnecting pore structure absorb more water than normal weight aggregates. One important effect of the aggregate absorption is the amount of water allowable in the concrete mix which leads to loss of concrete workability (Liu, 2005). The test results presented in Table 1 show that the water absorption of PKS and granite aggregates were 18% and 0.68% respectively. Since the value obtained for the PKS is higher, it is reasonable to conclude that the PKS will absorb higher amount of mixing water during concrete production.The Concrete Society of the UK (1987) states that water absorbed by LWAs may vary from 5% to 25% by mass of dry aggregate, as opposed to about 2% for most normal weight aggregates. Studies have also shown that pre-soaking the PKS prior to producing the concrete goes a long way to overcome the phenomena of diluting the concrete with increased water (Mannan & Ganapathy, 2002, 2004; Olanipekun *et al.*, 2006).

Table 1: Physical Properties of Aggregates

Properties	PKS (LWA)	Granite (NWA)
Maximum aggregate size, mm	14	14
Shell thickness, mm	1 – 5.9	-
Specific gravity, saturated surface dry	1.35	2.65
Aggregate impact value (AIV), %	3.01	13.5
Aggregate crushing value (ACV), %	5.3	25.7
Los Angeles Abrasion Value (AAV), %	4.73	19.6
24-hour water absorption, %	18	0.68
Flakiness Index (%)	63.2	31
Elongation Index (%)	16.6	22
Moisture content (%)	9.7%	-

- *Specific Gravity:-* Specific gravity is used in the computation of voids in aggregates. The test results presented in Table 1 show that the specific gravity obtained for the PKS is 1.35. The high porosity of PKS may have contributed to the low specific gravity value obtained compared with the specific gravity obtained for the granite aggregate of 2.65 (Table 1), which is considered adequate for normal weight aggregate (Adom-Asamoah & Russell, 2010).The results obtained imply that for a given mix proportion, the PKSC would contain a much higher volume of coarse aggregate than the NWC, if weight batching is used.

- *Aggregate Impact Value (AIV):-* The AIV obtained for PKS and granite are 7.46% and 13.5% respectively (Table 1).Aggregate Impact Value indicates the degree to which the aggregates absorb shock (Teo *et al*., 2007), indicating that the PKS has a greater degree of absorbance to shock than the granite. The BS 882 (1992) sets the limiting value of AIV at 25%, for materials which are adequate for concrete. Lower modulus of elasticity and higher tensile strain capacity of lightweight aggregates give their corresponding concrete better impact resistance than normal weight concrete.

- *Aggregate crushing value (ACV):-* The ACV gives the relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. The crushing values obtained for the PKS and the granite aggregates are 5.3% and 25.7% (Table1). BS 812 (1990) recommends that the ACV should not exceed 30%. The results show that palm kernel shell aggregates are stronger under loads than the normal weight aggregates. Although, both types of aggregates are suitable for the production of normal concrete, PKS concrete are expected to be higher than that of normal weight concrete.

- *Los Angeles Abrasion Value (AAV):-* The Los Angeles Abrasion Valueor Aggregate Abrasion Value (AAV) is used to measure aggregate's ability to resist surface wear to due traffic. The results obtained for the AAV are 5.1 and 15.93 for PKS aggregates and granites respectively (Table 1). The abrasion value of coarse aggregates should not be more than30% for wearing surfaces and 50% for concrete other than wearing surfaces (Shetty, 2005). The AAV obtained for the PKS implies that concrete made from PKS aggregate will possess a high degree of resistance to wear as compared to the granite aggregates. It is therefore evident that PKS can be used in the production of concrete intended for floors and pavements where human traffic is expected to be heavy.

- *Density of Concrete:-* The results of the density tests presented in Table 2show an average density of 1834 Kg/m^3 for the PKS concrete and 2348Kg/m^{3}for normal weight concrete. The PKS concrete is about 22% lower in density than the normal weight concrete. Lightweight concretes normally have densities lower than 2000 Kg/m^3 (American Concrete Institute ACI 213R, 2003; EuroLightCon, 1998). Thus, the PKS concrete produced in this study is a lightweight concrete. The higher specific gravity of granite aggregate and higher sand content in the NWC resulted in higher concrete density. On the other hand, the lower specific gravity of PKS and lower sand content contributed to lower density of the PKSC. From Table 2, one can observe that the compressive strength of both PKS and normal weight concretes directly depend on the unit weight of the corresponding concrete, the lower the unit weight of concrete the lower the compressive strength.

Table 2: Density of PKSC and NWC

Mix ID	Density (At Age of Testing), Kg/m^3		
	7 days	14 days	28 days
PKSC-A	1809	1820	1864
PKSC-B	1810	1815	1888
NWC-A	2318	2336	2377
NWC-B	2332	2348	2376

Compressive Strength

The compressive strengths of the PKSC and the normal weight concrete tested on 7, 14 and 28 days are presented in Figure 4. The compressive strength values are in the range of 19.11N/mm^2 to 27.47 N/mm^2 for PKSC and 24.23 N/mm^2 to 37.62 N/mm^2 for the normal weight concrete. The 28-day strengths of PKSC produced from Portland-limestone cement and Ghacem Extra cement are 24.87 and 27.47N/mm^2 respectively, while that of the normal weight concrete produced from Portland-limestone cement and Ghacem Extra cement are 33.29 and 37.62 N/mm^2. The28-day compressive strength of PKSC produced from Portland-limestone cement was about 21% to 25% lower than the corresponding normal weight concrete. On the other hand, the 28-day compressive strength of PKSC produced from Ghacem Extra cement were about 26% to 27% lower than that of normal weight concrete. For the same water/ cement ratio, the superior strength of normal weight concrete to PKSC could be attributed to the rough surface structure, good inter-facial bond between the aggregates and the cement matrix, and density of the crushed stone aggregates. The results show that the strength of the PKSC produced from Portland-limestone cement is approximately 46% higher than the minimum required strength of 17N/mm^2 for structural lightweight concrete recommended in ASTM C330 (1999) and approximately 66% higher than the minimum required strength of 15N/mm^2

recommended in BS 8110 (1997) (Fig. 4). This result compares well with the findings of Liu (2005) who reported of a 28-day compressive strength of 26.5N/mm^{2}for pumice aggregates.

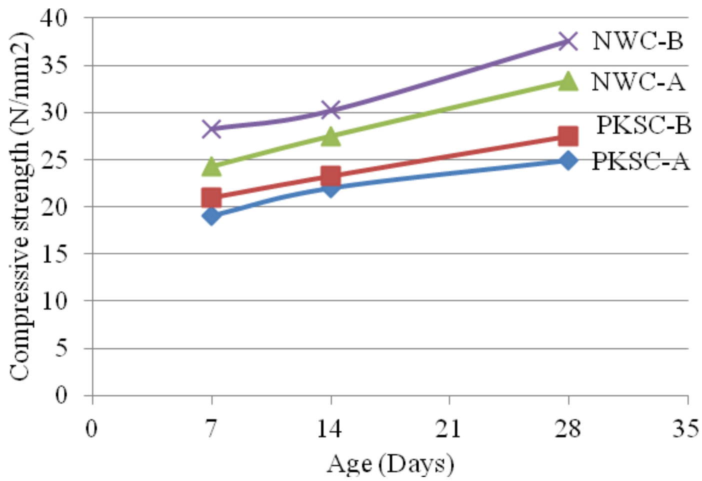

Fig. 4 Compressive Strength of PKSC and NWC

The failure of the PKS concrete was observed to have been caused by a weak bond between the PKS and the cement matrix. This could be attributed to the flaky and elongated PKS aggregates and the smooth convex surfaces of the PKS aggregates which results in a weak bond between the PKS and the cement matrix.Newman (1993) reported that the strength of lightweight aggregates was the primary factor controlling the upper strength limit of LWAC. The mode of failure of the PKSC observed in this study, however, suggests that the strength of PKSC depends on the strength of the mortar and the interfacial bond between the PKS and the cement matrix.

Fig. 5: Failure of PKS aggregates

Fig. 6: Failure of granite aggregates

It was also observed that for the normal weight concrete, failure was explosive, resulting in full disintegration of the test specimens (failure of the granite aggregates) (Fig. 5 and 6). For the PKS concrete, however, failure was gradual and the specimens were capable of retaining the load after failure without full disintegration. This may be attributed to the good energy absorbing quality of the PKS aggregates derived from the low AIV and ACV shown in Table 1 (Teo *et al*., 2007). This behavior of the PKS aggregates is beneficial to concrete structures that require good impact resistance properties.

Conclusion

The study has shown that the physical and mechanical properties of the palm kernel shell aggregates are satisfactory for producing structural concrete, and that the type of aggregates influences the unit weight and compressive strength of the corresponding concrete. The smooth convex surface of the palm kernel shell aggregates resulted in a weak bond between the PKS aggregates and the cement matrix. Thus, the strength of PKSC is usually governed by the strength of the mortar. The 28-day air-dry density of PKS concrete was within the range for structural lightweight concrete and was about 20% less than normal weight concrete. Ghacem Extra cement produced PKS concrete of higher strength compared to the Portland-limestone cement. The 28-day compressive strength of PKS concrete using Portland-limestone cement and the Ghacem Extra was approximately 25% and 27%

lower respectively compared to the granite concrete. PKSC can be used to produce concretes with compressive strength higher than the minimum required strength of 17N/mm^2 for structural lightweight concrete. The results of the study have shown that PKS has good potential as coarse aggregates for the production of structural lightweight concrete for low-cost housing construction. In this study, only the physical properties were considered, further studies that investigate the structural behaviour of palm kernel shell concrete beams is recommended.

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