

BOND AND FLEXURAL STRENGTH CHARACTERISTICS OF PARTIALLY REPLACED SELF-COMPACTING PALM KERNEL SHELL CONCRETE

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Abstract

Self-compacting concrete (SCC) is an innovative concrete that has helped in overcoming challenges associated with vibrated concrete such as congested reinforcements, noise from vibrators, and cost of hiring vibrators. This research examined the bond strength between partially replaced Self Compacting Palm Kernel Shell (SCPKS) concrete and high yield reinforcing bars wherein the granite content of the concrete was replaced by 50% of palm kernel shell (total replacement disintegrated on removal of mould). SCPKS concrete specimens of mix ratios 1:2:4, 1:1.5:3 and 1:1:2 were produced and cured for 7 days, 21 days and 28 days at water to cement ratio (w/c) of 0.5 and 0.6 respectively. Flow, bond strength, and flexural tests were conducted on the samples. The highest bond strength was recorded for mix ratio 1:1:2 at w/c of 0.5 when tested at 28 days with a value of 5.56 N/mm². This value is 0.072% higher than the 28th day strength of 5.52 N/mm² for SCC without replacement of the granite content. Also, the highest flexural strength was recorded for mix ratio 1:1:2 at w/c of 0.5 when tested at 28 days with a value of 6.88 N/mm². It was concluded that palm kernel shell can be safely used for partial replacement in SCC.

Keywords: Self Compacting Concrete, Palm Kernel Shell, Bond Strength, Flexural Strength, Water-cement ratio

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1.0 INTRODUCTION

Globally, Concrete is extensively used as a structural material. It is produced from cement, water, aggregates and sometimes admixtures in specified quantities. Aggregates constitutes about 75% of the concrete size and play a significant role in several concrete properties such as strength, durability and workability. Normal concrete contains sand as fine aggregate and granite or gravel as coarse aggregate. There is a growing interest in the use of waste materials as an alternative aggregate materials and significant research have been made on the use of some different materials as aggregate substitutes [1]. The cost of production of concrete is greatly dependent on its constituents and this influences the cost of buildings since concrete is one of the widely used material in the construction of buildings. Thus, there is a need to source for alternative aggregate to replace the conventional one [2]. Industrial wastes such as blast furnace

slag, coal ash, steel slag and agricultural wastes such as coconut shell, palm kernel shells (PKS) have been used by some researchers in replacement of aggregates in concrete for the purpose of recycling industrial and agricultural wastes. The use of concrete for various types of structures as described by [3] is due to its structural stability and strength. Generally plain concrete system does not have the ability to carry load in tension, once cracks develop in its cement matrix. To improve the tensile cracking and prevent concrete failure, reinforcement using steel bars is carried out within the concrete mass [4]. Steel serves as an effective reinforcement in concrete because it bonds well with concrete. The bond strength is influenced by design mix, grade of concrete and contact surface of the steel to the concrete [5].

Palm kernel shells (PKS) are the by-product of the oil palm tree which are native to western Africa and used in the production of palm oil [6]. PKS are usually considered as wastes and dumped

in the open thus constituting a nuisance in the environment with little economic benefits. [7] and [8] reported that the use of PKS will bring about a substantive reduction in the cost of concrete production. PKS come in various sizes such as 0-5mm for small sizes, 5-10mm for medium sizes and 10-15mm for large sizes. They are hard and carbonaceous with little commercial value instead creating disposal and waste management challenges [9]. Recently, the Nigerian government has advocated for the use of local materials in construction to reduce cost; this has resulted in sourcing and development of alternatives such as agro-based and non-conventional local construction materials to achieve the maximum benefits of agricultural wastes [10]. PKS are largely found in the riverine states in Nigeria [11].

Self-compacting concrete (SCC) was developed in Japan in 1983 as a means of overcoming the challenge of realizing durability of concrete structures owing to dearth of skilled labour. It was also developed to advance the sturdiness of concrete structures and they are cast in such a way that no additional vibrations are required for compaction. It has been of great economic benefit because of faster construction time, reduction in site manpower and achievement of better surface finishes [12]. SCC contains lesser quantity and smaller sizes of coarse aggregates compared to conventional vibrated concrete [13]. [14] opined that SCC is neither affected by the shape and quantity of reinforcement rods nor by the arrangement of a structure. The skills of workers also do not have influence on the outcome of SCC. The high-fluidity and resistance to segregation of SCC makes it possible to be pumped for longer distances. It flows freely and comes out with a smooth surface level after placing. SCC consists of cement, aggregates, water, chemical and mineral admixtures in varying proportions. Superplasticizers are the commonly used chemical admixtures and they modify the rheological properties of concrete. Mineral admixtures are utilized as extra fine materials in addition with cement and sometimes to replace cement [15].

[16] investigated the bond strength characteristics between self-compacting concrete and TMT bars where he concluded that owing to retarding effect of superplasticizer admixtures in the SCC mix, at early ages the development of bond strength was slow. Thus, in the application of SCC more attention is required for construction safety. Escalation in the dosage of superplasticizers in SCC decreases the total required water within the mix, but the test results revealed that this relationship is not linear. The relationship between bond strength and compressive strength of normal concrete is more consistent than SCC. Owing to the improvement of bond strength in SCC, application of SCC instead of normal concrete in construction can yield significant advantages. Use of carboxylic acid-based type of superplasticizer in SCC can produce more uniformity. [5] reported the bond strengths in Normal Cement Concrete (NCC) at 28 days as 5.85MPa and 3.60 for w/c of 0.5 and 0.6 respectively and that of SCC as 5.52MPa and 3.29 MPa at 28 days for 0.5 and 0.6 w/c respectively.

The aim of this research is to determine the bond strength between partially replaced Self Compacting Palm Kernel Shell (SCPKS) concrete and high yield reinforcing bars. It also determined the flexural strength of the concrete produced from the mixture.

2.0 METHODOLOGY

The materials used consist of palm kernel shells, sand, cement, and water. The Palm kernel shells were obtained from Igbaye, an oil producing village in Osun state, Nigeria. The shells were washed with hot water to eliminate impurities which could have adverse effect on concrete. The PKS were dried in the sun, sieved and put in polythene bags to prevent water from getting in contact with them. Coarse aggregate passing through sieve size 19mm and retained on sieve 4.75mm diameter was used in this research while natural river sand was used as fine aggregate. The cement used was Ordinary Portland cement (42.5MPa) manufactured by Dangote cement situated at Ibese, Nigeria, conforming to [17]. The specific gravity and water absorption of the fine and coarse aggregates used in the research are given in Table 1 and both conform to [18].

The specific gravity test was done in accordance with BS 1377:2 (1990) [18]. The samples were screened on BS sieve thoroughly to remove unwanted particles and other deleterious materials. The weight of empty density bottle was recorded as W_1 . The sample was filled into the density bottle and weighed; the weight was recorded as W_2 (weight of bottle + dry sample). The density bottle was filled gradually with distilled water to gauge mark, soon after the end of soaking, air entrapped and bubbles on the surface of the aggregate sample was removed by shaking the density bottle and the weight was recorded as W_3 (weight of bottle + dry sample + distilled water). Then the bottle was emptied and oven dried. The density bottle was then refilled with distilled water to the gauge mark and weighed as W_4 (weight of bottle + distilled water). Eq. 1 was used in determining the specific gravity of aggregate.

$$\text{Specific gravity } G_s \text{ of soil} = \frac{w_2 - w_1}{(w_4 - w_1) - (w_3 - w_2)} \quad (1)$$

In obtaining the water absorption for the materials, the samples were thoroughly cleansed to remove finer particles and dust. They were drained and then placed in a wire basket and immersed in distilled water at a temperature of 25°C for 24 hours. The basket and aggregates were then removed from the water and allowed to drain for five (5) minutes. Afterwards, the aggregates were gently emptied from the basket on to some dry clothes for surface-drying until the clothes were saturated. The materials were then emptied to other sets of dry clothes and exposed to the atmosphere away from direct sunlight till it was completely surface-dry. Then the aggregates were weighed and designated as 'A'. The aggregates were placed in an oven at a temperature of 105 °C for another 24 hrs. After removing from the oven, it was cooled, weighed and designated as 'B'. Water absorption was calculated from Eq. 2.

$$\text{Water Absorption} = \frac{A-B}{B} \quad (2)$$

Flow ability indicates the quality of concrete with respect to consistency, cohesiveness and the proneness to segregation. The tests were carried out in accordance to [19]. In determining the flowability of the concrete, a cone of height 12cm, top and bottom diameters 17cm and 25cm respectively was placed on a flat table. The table top was cleaned of all gritty materials and wet. The mould was kept at the center of the table and filled with concrete in two layers. The excess concrete which overflowed the mould was removed. The mould was then lifted

vertically. The table was then raised and dropped 12.5 mm for 15 times. The diameter of the spread concrete was measured in about 6 directions to the nearest 5 mm and the average spread was recorded. The flowability of the concrete was obtained as the percentage increase in the average diameter of the spread concrete to the base diameter of the mould.

SCPCKS concrete specimens of mix ratio 1:2:4, 1:1.5:3 and 1:1:2 were produced and cured for 7 days, 21 days and 28 days respectively while water to cement ratio of 0.5 and 0.6 were adopted in all mixes. 1% Superplasticizer (SP) by weight of cement was used throughout the mix. 100% replacement of PKS could not be investigated because it kept disintegrating after the removal of the moulds. Table 2 shows the mix proportion of the SCPCKS concrete.

In determining the bond strength of SCPCKS concrete, the pull-out specimens were tested with a 2000 kN capacity Universal Testing Machine (UTM) at the Materials and Structures Laboratory of the Osun State University, Oshogbo, Nigeria. The concrete cubes were attached to the UTM as shown in Figure 1. The reinforcement was held in place by the jaws on the upper deck of the UTM. In order to nullify the self-weight of the cubes the system was put in equilibrium by adjusting the space between the upper and middle deck with a non-loading motor. The UTM's rate of loading was set to 2250 kg/min after which

loading was commenced and records of the loads taken. The machine stops automatically when the specimen offered no resistance to the tensile force applied. The bond stress corresponding to the maximum pullout load was computed from Eq. 3:

$$S = \frac{P_{max}}{\pi l d} \quad (3)$$

Where S = Bond strength, P_{max} = maximum pull-out load, D = diameter of the bar, and L = embedded bar length.

The flexural test was carried out in accordance with [20] using a UTM at the Materials and Structures Laboratory of the Osun State University, Oshogbo, Nigeria. After the required age of curing, the concrete beams were removed from the curing tank and allowed to surface dry. Thereafter, they were weighed on a balance to obtain the weight of each beam. The weighed beams were carefully and centrally placed in the UTM with the longitudinal axis of the beams at right angle to the longitudinal axis of the upper and lower rollers. The load was applied after ensuring that loading and supporting rollers were resting evenly against the beam. The flexural test (center point loading) setup is displayed in Figure 2.

Table 1 Specific gravity of Fine and Coarse Aggregate

Test sample	Specific gravity (SSD)	Absorption 24hr (%)
Fine Aggregate	2.65	3
Coarse aggregate (PKS)	1.28	24
Coarse Aggregate (Granite)	2.63	<1

Table 2 Mix proportion of SCPCKS concrete

Mix Ratio	W/C Ratio		Cement		SP		Fine Aggregates		Granite		PKS		Compressive strength (N/mm ²)
		Kg	(%)	kg	(%)	kg	(%)	kg	%	kg	%	kg	
1:2:4	0.5	2.2	100	4.4	1	0.44	100	10.44	50	12	50	5.2	14.8
	0.6	2.64	100	4.4	1	0.44	100	10.44	50	12	50	5.2	12.4
1:1½:3	0.5	3.3	100	6.6	1	0.66	100	11.7	50	13.5	50	5.9	10.7
	0.6	3.96	100	6.6	1	0.66	100	11.7	50	13.5	50	5.9	9.3
1:1:2	0.5	4.95	100	9.9	1	0.99	100	11.7	50	13.5	50	5.9	16.4
	0.6	5.94	100	9.9	1	0.99	100	11.7	50	13.5	50	5.9	15.1



Figure 1 Bond Stress Test Setup



Figure 2 Specimen beam under flexural test

3.0 RESULTS AND DISCUSSION

3.1 Flow ability test

The results for flow ability obtained for all the mix ratios considered in this research are shown in Table 3. The flow ability

of all the grades of concrete increased with increase in water cement ratio. This result shows that only the consistency for mix ratio 1:1:2 SCPKS concrete is adequate when compared with 650mm minimum value specified by [19].

Table 3 Flow ability of SCPKS Concrete

Mix ratio	w/c ratio	Flow ability (mm)
1:2:4	0.5	430
	0.6	510
1:1½:3	0.5	570
	0.6	640
1:1:2	0.5	650
	0.6	700

3.2 Bond Strength

The bond strength of SCPKS concrete for mix ratios 1:2:4, 1:1½:3 and 1:1:2 are shown in Figure 3, Figure 4 and Figure 5 respectively.

The bond strength of SCPKS concrete for mix 1:2:4 and 1:1½:3 at 0.5 w/c ratios were less than that of mix ratio 1:1:2. The maximum bond strength of 5.56 N/mm² for mix ratio 1:1:2

was recorded at 0.5 w/c ratio at 28 days. This value is 0.072% higher than the 28th day strength of 5.52 N/mm² used as the control bond strength as reported by [5] when the same moisture content was used for Self-compacting concrete with 100% granite aggregate. However, this value is 5% lower than the 28th day strength of 5.85 N/mm² for Normal vibrated concrete which also serves as the control bond strength as reported by [5] for the same water-cement ratio.

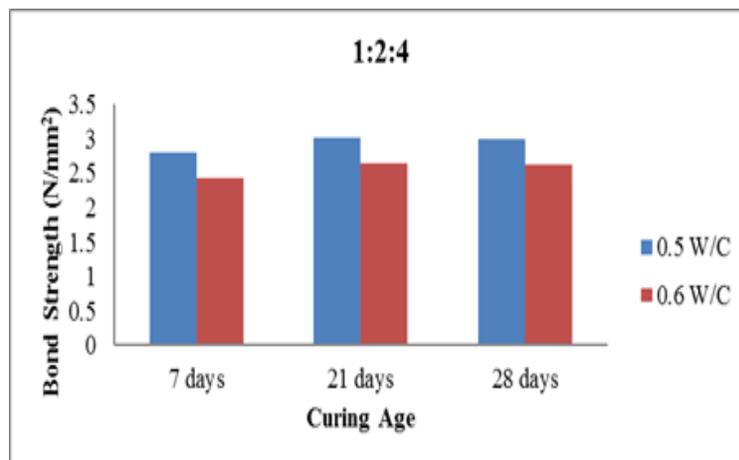


Figure 3 Bond Strength of Ratio 1:2:4 SCPKS concrete

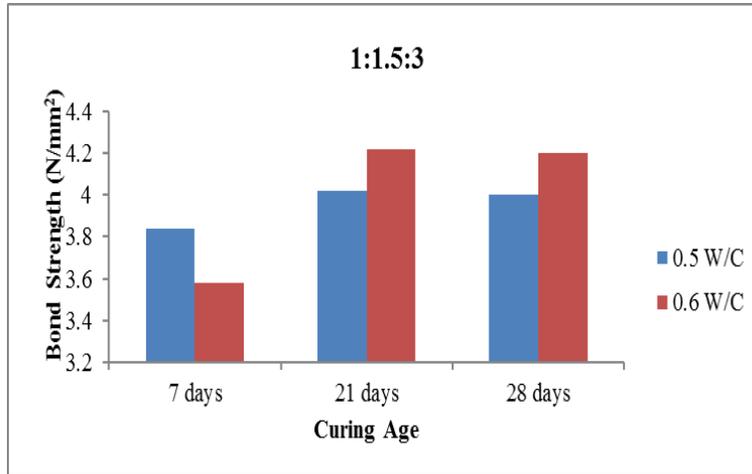


Figure 4 Bond Strength of Ratio 1:1.5:3 SCPKS concrete

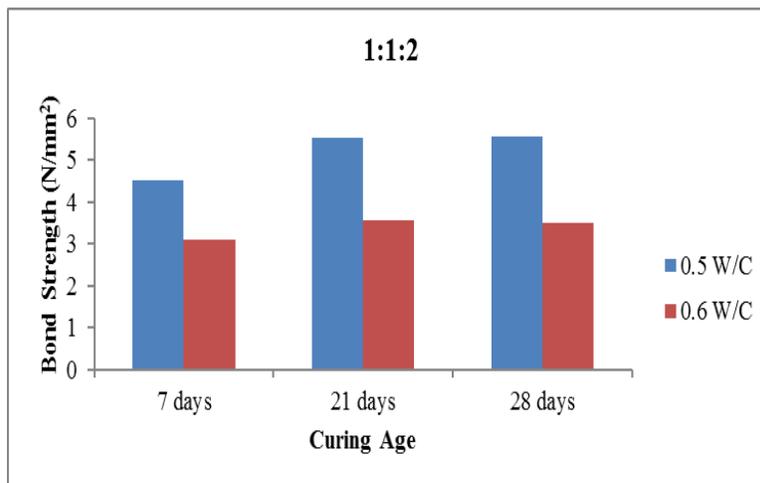


Figure 5 Bond Strength of Ratio 1:1:2 SCPKS concrete

3.3 Flexural Strength Test

The flexural strength results of mix 1:2:4, 1:1½:3 and 1:1:2 at different curing ages are shown in Figure 6, Figure 7 and Figure 8 respectively.

It was observed that, the flexural strength of the specimens increased as the curing days increased and the highest flexural strength of 6.88 N/mm² was recorded at 0.5 w/c ratio for mix 1:1:2. This strength is 109% greater than the value of 3.278

N/mm² reported by [21] for the flexural strength of Grade 20 concrete.

It was also observed that the beam specimens did not shear in tension showing that there is good bonding between the aggregates and the matrix. It was noted that with increase in dosage of water-cement ratio for each grade, flexural strength decreases.

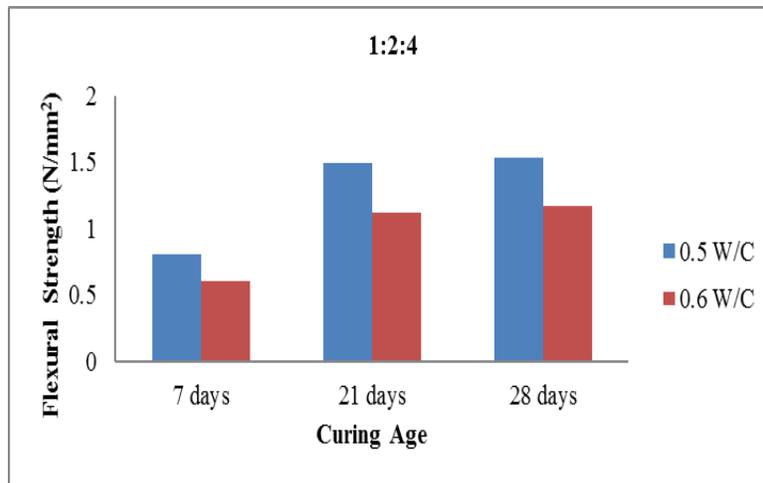


Figure 6 Flexural Strength of Ratio 1:2:4 SCPKS concrete

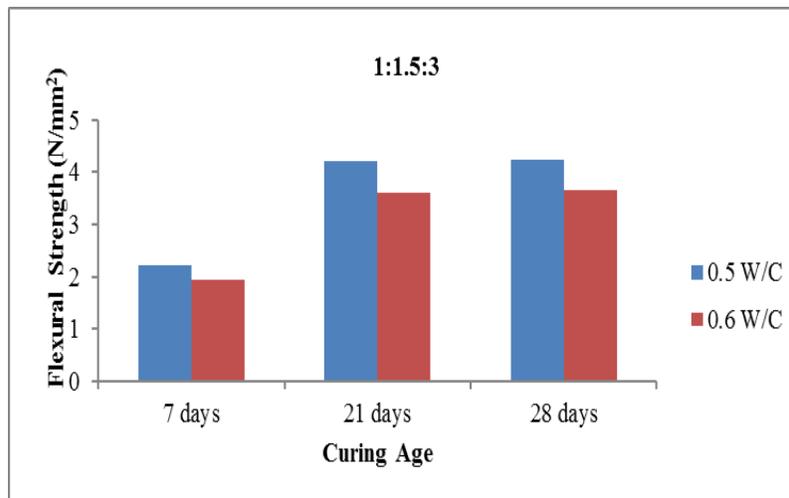


Figure 7 Flexural Strength of Ratio 1:1.5:3 SCGPKS concrete

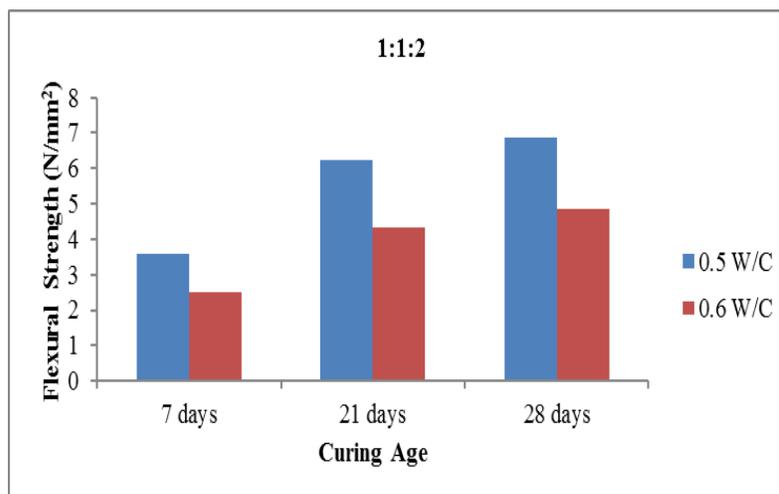


Figure 8 Flexural Strength of Ratio 1:1:2 SCGPKS concrete

4.0 CONCLUSIONS

The following conclusions were drawn from the research:

- i. Flow ability for all the mix ratios of concrete considered increased with increase in water cement ratio;
- ii. The bond strength of SCPKS concrete for mix 1:2:4 and 1:1½:3 at 0.5 w/c ratios were less than that of mix ratio 1:1:2. The maximum bond strength for mix ratio 1:1:2 was 5.56 N/mm² obtained at 28 days of curing. This value is 0.072% higher than the 28th day strength of 5.52 N/mm² for the bond strength of the control beam reported by [5] when the same moisture content was used for Self-compacting concrete with 100% granite aggregate. However, this value is 5% lower than the 28th day strength of 5.85 N/mm² for Normal vibrated concrete which also serves as control beam for this research as reported by [5] for the same water-cement ratio.
- iii. The flexural strength of the specimens increased as the curing days increased and the highest flexural strength of 6.88 N/mm² was recorded at 0.5 w/c ratio for mix ratio 1:1:2. This strength is 109% greater than the value of 3.278 N/mm² reported by [21] for the flexural strength of Grade 20 concrete.
- iv. Mix ratio 1:1:2 at 0.5 w/c ratio for SCPKS performs favourably when compared with normal vibrated concrete and is therefore recommended for use in structural works.

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