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Effectiveness of Palm Kernel Shell Ash Concrete Reinforced with Steel Fibres

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Abstract: *The steadily increasing cost of cement has made construction very expensive in many countries of the world, coupled with the adverse effect of cement production on the environment. To solve these problems, studies have been made on various materials like Pozzolans which could be used as partial replacement for cement in concrete production. Palm kernel shell ash (PKSA) is the ash produced from burning of palm kernel shell thus, PKSA is used as partial replacement of cement in this study. This study investigated the effect of palm kernel shell ash (PKSA) as a partial replacement with ordinary Portland cement in high strength palm kernel shell ash concrete reinforced with steel fibres. The properties studied includes workability of fresh concrete, compressive strength, flexural tensile strength, and water absorption for hardened concrete. PKSA contents in mixes ranged between 0% and 50% by weight of cement and Steel fibre of 0.75% by volume of concrete was maintained in all mixes containing steel fibre. The use of palm kernel shell ash (PKSA) has advantages like; reduction in cost of concrete, solving environmental pollution problems as well as reduced the number of landfill areas required for disposing the PKSA. The results indicate that the inclusion of steel fibre into concrete contained ordinary Portland cement concrete or PKSA, improved the tensile strength properties. Further, it was observed that increase in percentage of PKSA led to a corresponding reduction in both flexural and compressive strength when compared with control concrete. Since the strength reduced with further addition of PKSA from 25%, it is recommended that optimum replacement level of ordinary Portland cement by Palm kernel shell ash is 25% for good compressive and tensile properties.*

Keywords: *Palm kernel shell ash, steel fibre, cement, strengths.*

1. INTRODUCTION

Concrete is a synthetic construction material made by mixing of cement, fine aggregates, coarse aggregates and water in the proper proportions [1 - 3]. Each of these components contribute to the strength of the concrete. The introduction of new materials in today's construction market is the result of resource constraints, advances in engineering techniques and cost-serving measures. Steel, glass and synthetic fibres have been used with concrete, and research into new fibre reinforced concrete continues today. Plain concrete is a brittle material, with a low tensile strength and a low strain capacity [4]. The role of randomly distributes discontinuous fibres is to bridge across the cracks that develop within the concrete. The usage of fibres is to control plastic shrinkage cracking and drying shrinkage cracking [5]. Furthermore, other function is to lower the permeability of concrete and thus reduce bleeding in water. Depending on types of fibre used, some provide greater impact, abrasion and shatter resistance in concrete. While some fibres reduce the strength of concrete. The use of fibres also alters the behaviour of the fibre-matrix composite after it has cracked, thereby improving its toughness [6].

Attempts have been made by various researchers such as [7 - 10] to reduce the cost of concrete and total construction cost by investigating and ascertaining the usefulness of alternative materials feasible for use in construction. The utility of fly ash as partial replacement in concrete mixes is on the rise. The quantity of fly ash produced from power plants in India is approximately 105 million tonnes each year [11]. The production of cement is increasing annually by about 3% which allows the production of one tone of cement liberates about one tone of CO2 to the atmosphere [12]. The contribution of Portland cement production worldwide to the greenhouse gas emission is estimated to be about 1.35 billion tonnes annually to the earth's atmosphere [13]. Cement is also among the most energy intensive construction materials.

Palm kernel shell ash (PKSA) has the potential to be used as a construction material. PKSA is the ash produced from husk fibre and shell of palm oil burning by generation plant boiler which generates energy to be used in palm oil mill to extract palm oil [7]. PKSA is found to have high pozzolans material which can increase the compressive strength and durability of concrete. The aim of this study is to investigate the potential of producing high strength concrete by partial replacement of cement with palm kernel shell ash in a steel fibre reinforced concrete. The Specific objective of this research is to design a high strength concrete mix with a targeted strength of 50MPa. Additionally, the compressive strength, flexural strength and water absorption test of high strength - palm kernel shell ash steel fibre reinforced concrete were determined.

2. MATERIALS AND METHODS

2.1 Materials

The materials used for this research works includes Cement, Palm kernel shell ash, Steel fibre, Aggregates, Water, and Super plasticizer. In this investigation, Ordinary Portland Cement obtained from Lafarge Company of 53 grade was used in the study. It conforms to BS 12, (1996) and BS 4550 parts, (1978). The palm kernel shell ash was obtained from a black smith workshop in Igbara – Odo Ekiti, Ekiti State, Nigeria. The ash was sieve using sieve number 0.425mm and only ash particles that pass-through the sieve was used in the concrete preparation. The Fine Aggregate used (i.e. Sharp sand) was sourced from Ajibode borrow pit in Ibadan, Nigeria. It was thoroughly washed with water to reduce the level of impurities and organic matter, and later sun dried. The fine aggregates (sand) particle sizes ranges from 0.10mm-6.0mm in diameter which conformed to the requirements of BS 882 (1982). The coarse aggregate used for the investigation was sourced from PW Construction quarry and crusher site located at Km 13+000 (Akinyele area) along the Ibadan – Ilorin dual carriageway, in Ibadan, Nigeria. Coarse aggregates of size 20mm were used in the preparation of the concrete.

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. Potable water was used in preparing the concrete specimens. The water used for the study was obtained from a borehole at PW Laboratory, Ibadan. The water was clean and free from any visible impurities. It conformed to BS3148 (1980) requirements. In concrete, the water-binder ratio is generally kept as low as possible and hence to obtain the given degree of workability, chemical admixtures, such as, super plasticizers were used. CONPLAST SP 430 was used throughout the investigation. The principal effect of this Superplasticizer admixture is its high range water reducing at equal consistency. It is a dark brown coloured liquid complying with BS 5075 part III and ASTM-C 494 Type F (as provided by the manufacturer). The specific gravity is 1.19±0.01 kg /l at 20°C and solid content is 43% by mass.

Hooked end steel fibre imported from UK was used in the study. The fibre consisted of independent units which could be put directly in bunches in the concrete mix and then allowed to scatter uniformly throughout the concrete mix by mechanical action. The properties of the fibre used were gotten from the manufacturer and are described in Table 1.

Table 1: Steel fibre properties

Property	Specification
Shape	Hooked end
Length	25mm
Diameter	0.38mm
Aspect ratio	I/d = 25/0.38 = 65.79
Ultimate Tensile Strength	795Mpa
Density	7890g/mm^3

2.2. Mix Proportioning of concrete

In this study, control mix which was designated as G was designed to achieve a target compressive strength of 50MPa. Palm kernel shell ash was used to replace ordinary Portland cement at various levels of 25% and 50% by mass of binder content. The steel fibres of 0.75% by volume fraction of concrete were used. The mix proportions of different mixes are shown in Table 3. Two types of investigations were carried out. The first investigation was the preliminary investigation in which the DOE method was used to design trial mixes for grade 50 concrete. After the preliminary investigations, a specific design mix was then adjusted for final experimental investigations in which the PKSA was used as partial replacement for cement in plain concrete.

2.2.1 Preliminary Investigations

The DOE method of concrete mix was used as a guide for the design of the initial concrete mix proportion. The design target at 28 days is 50N/mm2. Below is the calculation of the concrete mix.

Design of Concrete Mix

Control concrete

Targeted Concrete Strength at 28 Days =50MPa
Specific Gravity of fine aggregate = 2.63
Specific gravity of Coarse Aggregate = 2.72
Fineness modulus of fine aggregate = 2.67
Assumed Standard Deviation = 8 MPa
Absorption of C.A. = 1%

(i) Obtain the target mean strength

Assume 5% of results fall below specified strength

Target Mean strength, $f_m = f_{\min} + k_s$

$k_s = 8 * 1.96 = 15.68 MPa$

$f_m = 50 + 15.68 = 65.68 MPa$

(ii) Find out the water/cement ratio for 65.68MPa concrete (G50 Concrete)

For crushed aggregate, W/C ratio of 0.5, 28 days' compressive strength is 49 MPa. By finding the intersection point for 49MPa and 0.5 W/C, a dotted line curve is drawn parallel to the neighboring curve. From this curve, the W/C ratio is being read for a target mean strength of 65.68MPa.

The water cement ratio = 0.4

Taking durability into consideration, the water cement ratio recommended = 0.45

Thus, W/C ratio of 0.40 (the minimum of the two values) was adopted.

(iii) Decide water content for the required workability (i.e. Slump or Vebe time)

The water content for a slump of 60mm (assumed) using a naturally occurring fine aggregate and crushed 20mm (max. size) coarse aggregate. Water content required = 210 kg/m^3

(iv) Obtain the cement content

Required cement content $= \frac{210}{0.4} = 525 kg/m^3$

(v) Determination of density of wet concrete

Wet Density of Fresh Concrete = 2410 Kg/m^3

(vi) Total aggregate content

20mm crushed aggregate of specific gravity 2.70

The wet density = 2410kg/m^3

Weight of total aggregate =2410 – (525+210) = 1675kg/m^3

Weight of Fine Aggregate = $1675\ X\ 38/100=$ 636.5kg/m^3

Weight of Fine Aggregate =1675 –636.5= 1038.5 kg/m^3

vii) Palm kernel shell ash content

For 25% OPC replacement = $525\ x$ .25= 131.25kg/m^3

For 50% OPC replacement = $525\ x$ .50 = 262.50kg/m^3

Table 2: concrete mix design

Quantities	Cement (kg)	Water (Kg)	Fine Aggregate(kg)	Coarse Aggregate(kg)
Per m^3	525	210	637	1039
per trial mix of 0.005 m^3	2.63	1.05	3.19	5.20

The quantity by weight of each concrete constituent per m3 is stated above. This design was used to make three trial mixes of 0.005m3 from which the workability was determined immediately, and the compressive strength was tested after 7days successively. Base on the 7 days compressive strength test results for the trial mixes which fell slightly short of the expected results; adjustment was made to the design above and was adopted as the optimum mix design for this study.

Table 3: Summarized Concrete Design for all Mixes

MIX No.	MIX ID.		Mix Proportion	WATER (Kg)	CEMENT (kg)	PKSA (Kg)	CA (kg)	FA (kg)	SF (kg)	SP (L)	W/C
1	G	Per m^3	Control concrete	170	425	-	1083	722	-	88.54	0.4
2	F	Per m^3	Concrete with 0.75% steel fibre	170	425	-	1083	722	60	123.9	0.4
3	KK	Per m^3	Concrete with 25% PKSA and 0.75% steel fibre	170	318.75	106.25	1083	722	60	123.9	0.4
4	O	Per m^3	Concrete with 50% PKSA and 0.75% steel fibre	170	212.50	212.50	1083	722	60	88.54	0.4

2.3. Experimental Methodology

2.3.1 Compressive Test Strength

Eleven cubic specimens of 100mm x 100mm x 100mm each were cast. The specimens were tested to determine the compressive strength at 7, 28 and 56 days of curing; this was done in accordance with to BS EN 12390-3 (BSI, 2002). As earlier mentioned, eleven cubic specimens of dimensions 100mm×100mm×100mm were cast for each concrete mix of varying PKSA content and steel fibre content. The specimens were removed after 24 hours and cured under water in a curing tank. Three each of the cubes were tested to determine the compressive strength at 7, 28 and 56 days. It was done in accordance with BS EN 12390-3 (BSI, 2002). After the specimen have been soaked and removed from the curing tank, the specimens were taken to the electronic testing machine where load was applied and increased until failure. The machine automatically stops when failure occurs, and then displays the load and the compressive strength was evaluated. The compressive strength of each sample was determined as ratio of the crushing load (N) to the area of cube (mm2).

2.3.2 Flexural Strength Test

The specimens used for flexural tests were 100 x 100 x 500 mm. The flexural test was performed according to BS EN12390-5 (BSI, 2000). The test was carried out with the automatic techno test flexural machine at The Polytechnic Ibadan, Oyo state, Nigeria. Three cylindrical concrete specimens of 100mm x 150mm each were cast. Also, water absorption properties for each mix were determined. This was carried out at the PW construction company structural laboratory, Moniya, Ibadan. The cube specimens were tested at 7th, 28th and 56th days of curing and each day three samples were tested. That of the Prism were tested on the 28th of curing and the cylindrical specimens were tested on the 56th days of curing. Water Absorption was done on the 56th days of curing.

3. Results and Discussion

3.1 Workability

The workability of concrete was carried out throughout all the concrete series mixes and measured by Slump test. The result gotten is presented in Table 4.

Table 4: Results of the Slump test carried out on fresh concrete

MIX NO.	MIX ID	SLUM (mm)	Difference (%)
1	G	120	0
2	F	101	-16
3	KK	85	-29
4	O	74	-38

The measured slump values for the concrete mix ranges from 74mm to 120 mm respectively and the difference in percentage dropped/gained for all mix batches compared to control batch as shown in table 5. It was observed that the slump values of concrete contained PKSA when compare with control concrete decreases as the percentage of ash increases. This is mostly because of a lesser amount of available free water in the presence of PKSA. Furthermore, the effect of steel fibre content shows an adverse effect on the workability of the concrete. As shown in table V the slump values of concrete contained steel fibre has a decreasing trend when the PKSA rate increases. These results show that the higher the PKSA rate, the lower the workability of concrete. Also, the geometry and shape of the fibres is another factor that influences the workability and consistency of concrete.

3.2 Compressive Strength Test

Compressive strength was tested using direct compression testing on 100mm cubes. The maximum load for failure was obtained and the average of the compressive strength of three samples was reported in this study at each age of test.

Table 5: Compressive strength at 7, 28 and 56 days respectively

Mix No	Mix ID	7days (MPa)	28 days (MPa)	56 days (MPa)
1	G	35.97	42.06	47.14
2	F	41.32	53.37	55.18
3	KK	35.28	48.65	55.40
4	O	23.52	39.98	49.07

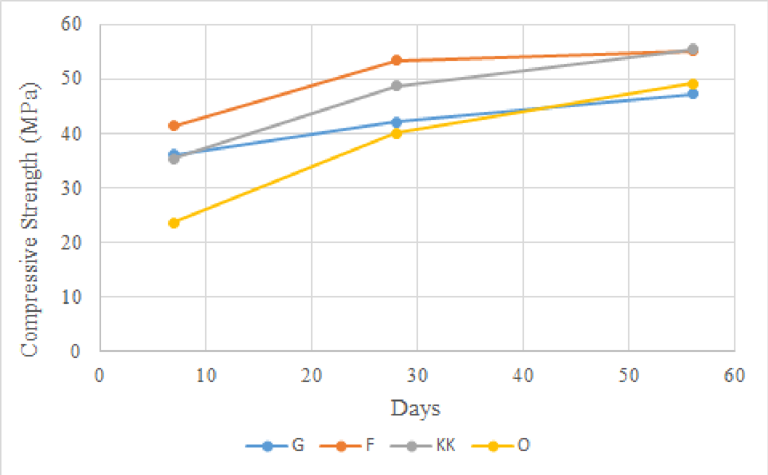

Figure. 1: Compressive strength development with respect to age of different concrete Mix

The summary of compressive strengths of the concrete mixes measured at 7, 28 and 56 days are presented in Table 5, It was observed that, under compressive loading for specimens without fibres, extensive cracks were produced in the concrete during the pre-peak stage and then suddenly failed at peak load (brittle failure). When steel fibres were added to the concrete, the propagation of the cracks was restrained due to the bonding of fibres into the concrete (ductile failure). These results support the conclusions of Trottier and Bantha (1994). Table VI shows the variations in mix compressive strengths. The compressive strength of concrete that contained 0.75% of steel fibre without PKSA has a higher value than the control concrete compressive strength from early and all stages. At 28 days, control mixture G (control concrete) achieved compressive strength of 42.06 MPa, whereas other mixtures F, KK and O achieved compressive strength of 53.37, 48.65 and 39.98 MPa, respectively. The addition of steel fibres to the concrete mixture did not improve its long term compressive strength. The 25% and 50% replacement level of PKSA mixes (KK and O) the compressive strength is low at 28 days but improved at 56 days for all percentage of Steel fibre addition. It was observed that steel fibres did not recover the compressive strength loss of PKSA. Figure 1 further illustrates the compressive strength results.

3.3 Flexural Strength test

The specimens were loaded and tested in accordance with the BS EN12390-5 (BSI, 2000). The three-point loading method was adopted with the forces applied perpendicularly to the beam without eccentricity. Loading is done continuously without any shock. The reaction was parallel to the direction of the applied force always and the ration between the point of loading and the nearest reaction to the depth of the beam was not less than one. Flexural strength of the concrete prisms is shown in Table 6. The flexural strength reported is the ultimate flexural strength.

Table 6: Flexural strength of prism at 28 days

Mix No	Mix ID	28 days (MPa)
1	G	3.94
2	F	4.86
3	KK	3.36
4	O	2.75

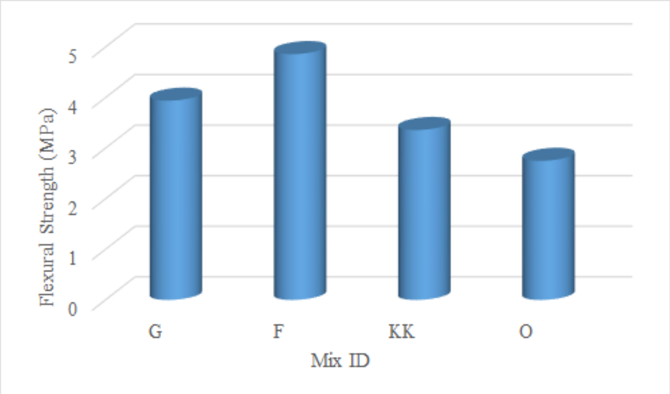

Figure 2: Graph showing variation of flexural strength for different concrete specimen

From figure 2, the flexural strength at 28 days of control mixture G (control concrete) was 3.94 MPa and for mixture F (0.75% steel fibre) was 4.86 MPa. The flexural strength of other mixes KK and O achieved strength of 3.36 and 2.75 MPa respectively. The flexural strength values of concrete with palm kernel shell ash (PKSA) when compared with the control concrete were reduced by 33.5% and 38%. Increases of 24% in flexural strength value of concrete contain 0.75% steel fibre (F) was observed when compare with the control mix. It was observed that the flexural tensile strength increased with age and reduced with increase in PKSA.

3.3.1. Load and Corresponding Deflection of Control Mix and all Mixes containing Fibre

The corresponding deflection as the prisms were loaded was gotten using a dial gauge. The deflection of all mixes containing fibre and the control mix are shown in Figure 3 - 6. For each of these mixes, the Load v/s deflection curves graphs were plotted and shown in the figure below.

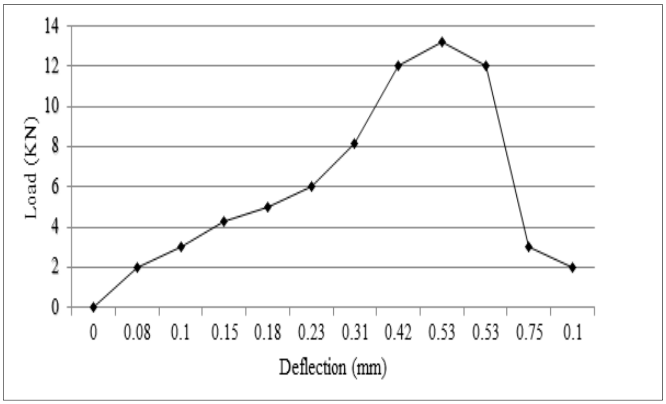

Figure 3: Load v/s Deflection curve of Mix 1: (G)

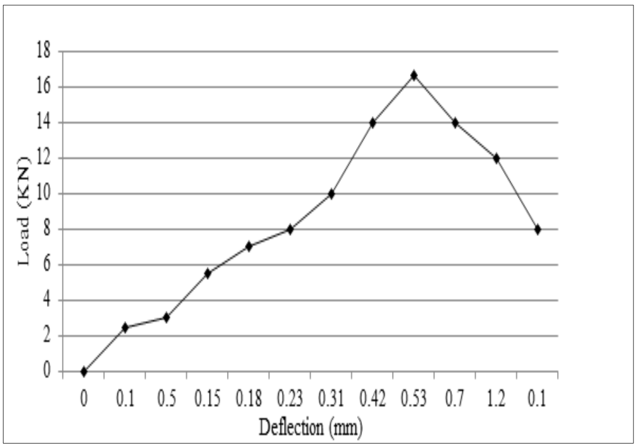

Figure 4: Load v/s Deflection curve of Mix 2 :(F)

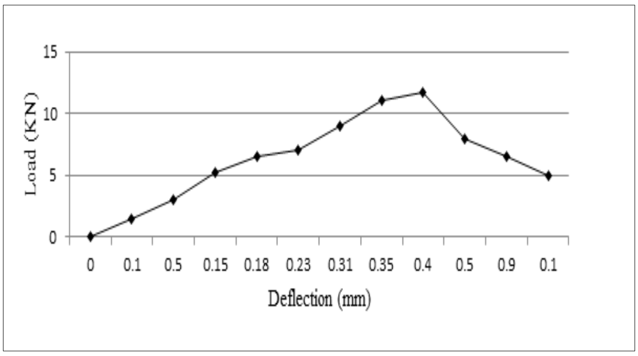

Figure 5: Load v/s Deflection curve of Mix 7 :(KK)

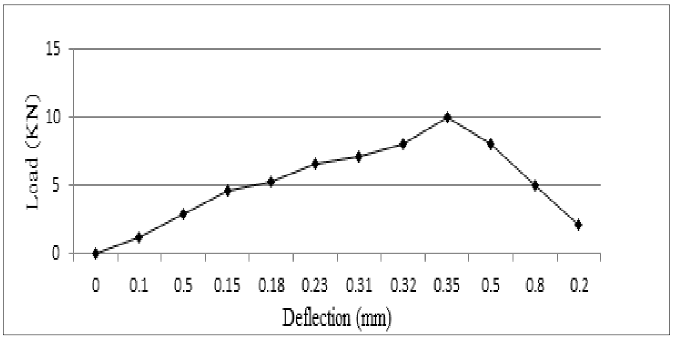

Figure 6: Load v/s Deflection curve of Mix 8 :(O)

It was observed that the deflection is relatively very higher after cracking of the specimen. The behaviour of the specimens is plastic as compared to brittle behaviour in concrete without fibre. With increase in palm kernel shell ash percentage the ultimate flexural strength decreases.

3.4 Water Absorption

The durability of each concrete mix was determined by their water absorption property. This was evaluated according to ASTM C642. The results are presented in Table 7. The incorporation of steel fibres improves the water absorption properties of the material because of the reduction of permeable voids. It also reduced by increment in cement replacement by palm kernel shell ash. This was attributed to the increase in density and reduction in capillary porosity caused by reaction products such as calcium silicates and calcium aluminates, which change the material microstructure. Increase in cement replacement with palm kernel shell ash (PKSA) also reduced the water absorption of concrete. This was because of high mortar volume and less voids as compared to concrete without PKSA. The lowest water absorption was observed for the concrete with highest cement replacement concrete.

Table 7: Water Absorption at the end of 56 days

Mix No	Mix ID	Initial weight (g)	Final weight(g)	Change in weight (g)	% CHANGE	Average
1	G1	2753.60	2688.10	65.50	2.38	
	G2	2778.30	2711.00	67.30	2.42	2.40
2	F1	2578.50	2524.21	54.29	2.11	
	F2	2607.22	2552.12	55.10	2.12	2.12
7	KK1	2578.65	2534.50	44.15	1.71	
	KK2	2596.60	2550.25	46.35	1.78	1.75
8	O1	2507.05	2465.23	41.82	1.67	
	O2	2534.00	2495.85	38.15	1.51	1.59

3.5 Cost Analysis

This analysis was done under three section for a unit of concrete (1.0m3). Firstly, cost analysis for plain concrete was done, and then concrete containing 25% of PKSA as partial replacement of cement was analysed. The results are presented in Table 8-9.

Table 8: Cost Analysis for 1m^3 of Plain Concrete

NO.	Description	Quantity Required	Unit	Rate (Naira)	Amount (Naira)
1	Cement	425	Kg	34	14,450.00
2	FA	722	Kg	2	1,444.00
3	CA	1083	Kg	3.50	3,790.50
4	SP	1.28	Kg	75	95.63
5	Water	170	L	0.8	138.00
6	Workmanship	-	-	-	6,000.00
7	Overhead	-	-	-	4,000.00
		TOTAL			**29,918.13**
		CONTINGENCY (5% of Total Cost)			**1495.91**
		Overall total for 1m^3			**31,414.04**
		COST FOR 0.038m^3			**1,193.73**

Table 9: Cost Analysis for 1 m^3 of Concrete containing 25% PKSA

NO.	Description	Quantity Required	Unit	Rate (Naira)	Amount (Naira)
1	Cement	318.75	Kg	34	10,837.50
2	PKSA	106.25	Kg	10	1062.50
2	FA	722	Kg	2	1,444.00
3	CA	1083	Kg	3.50	3,790.50
4	SP	1.28	Kg	75	95.63
5	Water	170	L	0.8	138.00
6	Workmanship	-	-	-	6,000.00
7	Overhead	-	-	-	4,000.00
		TOTAL			**27,368.13**
		CONTINGENCY (5% of Total Cost)			**1365.41**
		Overall total for 1m^3			**28,736.53**
		COST FOR 0.038m^3			**1,091.99**

Saving per cubic meter of concrete = 1,193.73-1,091.99 = 101.74 Naira
Percentage Savings = (101.74/1,193.73) * 100 = 8.52%

From the analysis above, it was observed that there were reductions in cost up to 8.52% for every cubic meter of concrete with 25% quantity of palm kernel ash as a partial replacement for cement during the concrete production in this study.

4.0. CONCLUSIONS

Steel fibre reinforced concrete with partial replacement of cement with palm kernel shell ash (PKSA) was investigated for its mechanical and durability properties. It was observed that the inclusion of steel fibre reduced workability with increasing fibre content. The incorporation of palm kernel shell ash (PKSA) as a partial replacement of cement in fresh steel fibre reinforced concrete also decreases workability when compared to control concrete made without PKSA. Further, the addition of steel fibres into concrete mixture did not improve its ultimate compressive strength of 7 days curing specimen, but after 28days and 56days only small increase in compressive strength with addition of steel fibre content was observed. It was noticed that steel fibres did not recover the compressive strength loss of palm kernel shell ash. Steel fibres have shown more significant effects on flexural tensile strength at 0.75% volume fractions used in this study. The inclusion of steel fibres improves the water absorption properties of the material because of the reduction of permeable voids. Increasing in palm kernel shell ash as a partial replacement of cement also reduced the water absorption of concrete. Based on the results of this study, the following recommendations are made: It was recommended that optimum replacement level of ordinary Portland cement by Palm kernel shell ash is 25% for good compressive and tensile properties, since the strength reduced with further addition of PKSA from 25%. It can also be recommended to carry out the investigation of this material for the rest of durability aspects of high strength concrete that not yet be investigated such as Rapid chloride penetration and Alkali silica resistance tests. The steel fibres are mostly used fibre for fibre reinforced concrete out of available fibres in market. According to many researchers, the addition of steel fibre into concrete creates low workable or inadequate workability to the concrete, therefore to solve this problem; super plasticizer should be added to the concrete without affecting other properties of the concrete.

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