COMPARATIVE STUDY AND EMPIRICAL MODELLING OF PULVERIZED COCONUT SHELL, PERIWINKLE SHELL AND PALM KERNEL SHELL AS A POZZOLANS IN CONCRETE

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Abstract. Infrastructural development across the world is fast growing due to the rapid growth in population. This has resulted in consequently creating an increase in the demand for construction materials, especially cement. This study presents a report of a concise investigation on the pozzolanic potentials of Pulverized Coconut Shell (PCS), Periwinkle Shell (PPS) and Palm Kernel Shell (PPKS). The chemical composition of the PCS, PPS and PPKS, physical properties of concrete constituents and mechanical properties of the pozzolans blended concrete were determined. A concrete mix ratio of 1 : 2 : 4 with a w/c of 0.6 was adopted. A total of 270 cubes and 120 cylinders were cast at an interval of 10 % from 0 % to 50 % replacement level and cured in water for 7, 14, 21 and 28 days. Results indicate that the PCS, PPS and PPKS are good retarders as they increased the setting time of cement paste and decreased the workability of concrete as the percentage replacement increased. The addition of the PCS in the mix produced a concrete of lower density while the addition of the PPS and PPKS produced a concrete of a higher density up to a 30 % replacement level, further increase resulted to a decrease in density. The compressive and tensile strengths increased with a curing age but decreased with an increasing percentage replacement level for the three pozzolans investigated. However, 10 % replacement level of the PCS, PPS and PPKS in concrete is suitable for the production of pozzolans blended concrete for structural works. The models developed are in a good agreement with the experimental results.

Keywords: Pulverized coconut shell (PCS), pulverized periwinkle shell (PPS), pulverized palm kernel shell (PPKS), structural strengths, empirical models.

1. Introduction

Infrastructural development across the world is fast rising, and this is consequently creating an increase in the demand for construction materials. Concrete is listed among the most extensively used construction materials worldwide and its production is daily on the increase to service the demand for the infrastructure development. Cement, which is the main binder in the production of concrete is very expensive; particularly in developing countries [1]. Besides its high cost, its production is associated with very high temperatures with an attendant emission of poisonous gases, such as CO_2, NO, NO_2, as well as depletion of natural resources such as limestone [2]. More so, due to increasing industrial and agricultural activities, tonnes of waste materials like as steel slag, palm kernel, rice husk, saw dust, groundnut husk, periwinkle shell, coconut shell, etc, are deposited in the environment without littleany effective method of waste management and recycling [3]. Some of these deposits are not easily decomposed and the accumulation has constituted to various forms of environmental challenges, hence there is a need to reuse them in order to minimize their negative effects on the environment.

The American society of testing materials (ASTM) [4] defines Pozzolans as siliceous or aluminous materials, which possess little or no cementitious properties but will, in finely divided form and in the presence of moisture, react with lime $[Ca(OH)_2]$ at ordinary temperature to form a compound having cementitious properties [5]. Many achievements have been made regarding to pozzolanic materials and the subject is still attracting much research due to its functional benefit of waste reusability and sustainable development, its indigenous technology and equipment requirements, and reduction in construction costs are added advantages.

Some findings of waste materials reveal a great significant effect on its mechanical properties of pozzolan blended concrete. Golewski [6], investigated the effect of the addition of siliceous fly ashes (FA) in the amount of 0, 20 and 30 % by weight of cement on the interfacial microcracks and mechanical parameters in plain concrete. He discovered that the using the 20 % FA cement binder could trigger favourable changes in the microstructure of concrete leading to an improvement in its mechanical properties. Also, the addition of fly ash into the concrete matrix up to 20 % resulted to a marginal increase of the fracture

toughness of plain concrete, while 30 % FA additive led to a significant decrease [7, 8].

Falade et al. [9], examined the Potential of Pulverized Bone as a pozzolanic material. Results of an investigation revealed no substantial difference in strength propertiesy of specimens having pulverised bone up to 20 % replacement at 28 days curing age when compared to the control specimens. From the results of the study, it was concluded that pulverised bone had pozzolanic properties and could be used to replace cement partially. Ikponmwosa et al. [10], investigated the Strength Characteristics of Concrete Beams with Cement Partially Replaced by Uncalcined Soldier-Ant Mound Clay. Results indicated that the addition of SAMC in the mix produced a concrete of a lower density than normal concrete; increased the setting times of cement with increased workability. The density as well as the flexural strength of concrete decreased with increase in SAMC content. However, 5 % SAMC content in the mix was considered as optimalum for an improved structural performance when compared with normal concrete. Ikponmwosa et al. [11], presented a study on the suitability of polyvinyl waste powder as a partial replacement for cement in concrete production. As part of their findings, polyvinyl waste powder has a pozzolanic effect, served as a retarder, reduced workability and higher structural strength up to a 20 % replacement. Reddy et al. [12], studied the utilization of sugarcane bagasse ash in concrete by a partial replacement of cement. The results showed that the performance of concrete having up to a 10 % SCBA replacement met the requirements of BS 8110 [13] and can be used for the production of concrete for structural works. Marthong [14], researched on the usage of sawdust ash (SDA) as a part replacement of cement in concrete production. The test results disclosed that the addition of SDA triggered only a little expansion due to a little calcium content. Early strength growth was observed to be around 50-60 % of their 28 days strength. It was recommended that the usage of SDA as a part replacement of cement should not exceed 10 % by volume in all grades of cement.

Utsev & Taku [15], studied the application of coconut shell ash as a replacement of ordinary portland cement in concrete production. The results revealed that the densities of concrete cubes for a 10-15 % replacement was were above 2400 kg/m^3 and the compressive strength increased from 12.45 N/mm^2 at 7 days to 31.78 N/mm^2 at 28 days curing; thus, meeting the requirement for the use in both heavy weight and light weight concreting. In conclusion, the study revealed that a 10 to 15 % partial replacement of the OPC with the CSA using a W/C ratio of 0.5 was suitable for a production of both heavy weight and light weight concrete. Umoh & Femi [16] investigated the behaviour of ternary blended cement concrete integrating periwinkle shell ash (PSA) and bamboo leaf ash (BLA) as cement enhancers. The result revealed that at 28- and 56-days hydration, ternary blended

cement concrete containing a combined percentage of PSA and BLA of 20 % cement replacement attained high compressive and tensile strength and low water absorption. Hence, from the result, it was concluded that blended cement concrete with a 20 % replacement of cement with the PSA and BLA was considered optimum for ternary blended cement concrete.

Offiong & Akpan [17] discovered, in the assessment of physico-chemical properties of periwinkle shell ash as part replacement for cement in concrete production, that Periwinkle shell ash calcined at 800 °C met the required maximum 34 % as stipulated by ASTM-C618 [18] is appropriate for the usage as a part replacement for cement in concrete production. As the percentage replacement level of PSA content increases, the strength properties of concrete reduces and the increase in curing age led to an increased strength for specimens cured in water (control); while for the specimen cured in sulphuric acid solutions, the strength properties decreased with age [19]. Similar findings were observed by Abdullahi and Sara [20] and Olutoge et al. [21].

Olutoge et al. [22] examined the strength properties of palm kernel shell ash concrete. From their research findings, the compressive strength for the PKSA blended concrete was lower than for a normal concrete but at a 10 % replacement, its 28-day strength of been 22.8 N/mm^2 is within the recommended strength for reinforced concrete. The combination of palm kernel shell ash with other Supplementary Cementitious Materials (SCM) had been researched and found to improve the strength properties of concrete [23, 24].

Utsev and Taku [15] investigated coconut shell ash as a partial replacement of ordinary Portland cement in concrete production. They discovered that the density of concrete increases with the increase in the CSA contents but the compressive strength decreases as the replacement level of CSA increases. It was concluded that a 10 % replacement level is optimal for replacing cement with the CSA. The decline in strength can be attributed to the nature of the CSA acting more as a filler material than a binding material [25]. Oyedepo et al. [26] carried out a study on the performance of coconut shell ash and palm kernel shell ash as partial replacement for cement in concrete. The results revealed that a 20 % PKSA and CSA replacement in cement gave an average optimum compressive strength of 15.4 N/mm^2 and 17.26 N/mm^2 , respectively, at 28 days. It was concluded that the optimum replacement level of a 10 % replacement is suitable for both light weight and heavy weight concrete production. Akhionbare [27] evaluated the usage of agro-waste as a partial replacements for cement in construction production. The seven selected agro-wastes are wood ash (WA), bone powder ash (BPA), acha husk ash (AHA), bambara ground shell ash (BGSA), rice husk ash (RHA), palm oil shell ash (POSA) and groundnut husk ash (GHA). The chemical analysis of the ash

for each material was done with the Bogue's model. A linear program calculates the equations governing the model for an ease of complex computations. The results revealed that bone ash (BA) has the highest compressive strength and C3S composition while rice husk is the most economically viable.

Global pollution coupled with resource depletion has inspired several engineers and researchers to search for these locally available resources with a view goal to investigateing their usefulness either wholly as a construction material or partly as a substitute for conventional ones in concrete production. The search revealed that Coconut Shell Ash, Periwinkle Shell Ash and Palm Kernel Shell Ash haves been used as a partial replacement of cement. However, little or no literature exists on the use of these three materials in their natural state (in pulverized form). Thus, this paper presents the comparative study between the characterization of pulverized coconut shell, periwinkle shell and palm kernel shell as pozzolans in concrete. This research is aimed at reducing the cost of concrete production and CO_2 emission by incorporating pozzolan (biodegradable waste) without compromising the concrete strength. Also, its serves as an encouragement for a low-cost housing scheme for real estate investors and developers.

2. MATERIALS & METHODS

2.1. MATERIALS

The cement used in this study was ordinary Portland cement (OPC), which conforms to the requirements set under ASTM C-150 [28], BS 12 [29] and BS EN 197-1 [30]. The pulverized coconut shell, periwinkle shell and palm kernel shell were gotten from matured shells at Badagry (Lagos state), Bariga (Lagos state) and Abeokuta (Ogun state), respectively. The shells were washed to remove impurities and sun-dried for 48 hours after which they were broken into small pieces and fed into a pulveriser. The powder from the pulveriser was then sieved using the sieve size with 90μm micron size. The shaft retained on the sieve was then collected and taken back to the pulveriser for a further processing.

Coarse aggregates were crushed granite ranging from 12.5 mm to 19 mm sizesin size, obtained from a quarry located in Ogun state. The fine aggregate used was river sand gotten from River Ogun, which was free from organic matter and salt. The gradation test as presented in Table 3 showed that they met specifications requirements in accordance to BS 882 [31]. The water used for this research was clean, portable and impurities-free obtained from University of Lagos Water Distribution System, which was in an accordance with BS 3148 [32].

2.2. METHODOLOGY

2.2.1. MIX DESIGN AND SAMPLE PREPARATION

The design mix proportions for Grade 30 concrete were 310.85 Kg/m³, 621.70 Kg/m³, 1243.40 Kg/m³ and 186.51 Kg/m³ for cement, sand, granite and water respectively, with a W/C ratio of 0.60 for one cubic meter of concrete. A total of 270 Nos. 150 mm × 150 mm × 150 mm concrete cubes and 120 Nos. 150 mm × 300 mm concrete cylinder specimens were cast, cured and tested. 90 cubes and 40 cylinders were cast using each of the materials at different replacement levels from 0 % to 50 % at 10 % intervals for pulverized coconut shell, periwinkle shell and palm kernel shell respectively. A concrete mixer was used for mixing the concrete constituents to produce freshly mixed concrete. The mixtures were poured into various moulds for different concrete elements and compacted using tapping rod and vibrating machine. The specimens were demoulded after 24 ± 2 hours and cured in potable water.

The specimens were de-moulded 24 ± 2 hours after the casting and stored in the curing medium until the age of the test of 7, 14, 21 and 28 days for the cubes and cylinders.

2.2.2. TESTING PROCEDURE

A Cchemical analysis was carried out on the PCS, PPS and PPKS in the Department of Chemistry, University of Lagos. Setting time test was conducted on the cement paste replacement with the PCS, PPS and PPKS. Also, workability was determined in the fresh state of the concrete having the PCS, PPS and PPKS using a slump test.

Compressive strength test was conducted using Avery Dension Universal Testing Machine having a loading rate of 120 kN/min, which was is in an accordance with BS EN 12390-3 [33]. The Ssplitting tensile strength test was done in an accordance with BS EN 12390-6 [34] and ASTM C496-96 [35] using a loading rate of 120 kN/min.

2.2.3. MATHEMATICAL MODEL

The results of and the experimental data for various properties of pozzolan blended concrete were analysed using a bilinear interpolation method to develop mathematical models for predicting parameters with respect to its variables. The algorithm for the bilinear interpolation method for the value of the unknown function f at points x and y. For a known value of f at four points; $Q_{11} = (x_1, y_1)$, $Q_{12} = (x_1, y_2)$, $Q_{21} = (x_2, y_1)$, $Q_{22} = (x_2, y_2)$. Linear interpolation in the x-direction, we have:

$$f_{x,y_1} = \frac{x_2 - x}{x_2 - x_1} f(Q_{11}) + \frac{x - x_1}{x_2 - x_1} f(Q_{21}) \quad (1)$$

$$f_{x,y_2} = \frac{x_2 - x}{x_2 - x_1} f(Q_{12}) + \frac{x - x_1}{x_2 - x_1} f(Q_{22}) \quad (2)$$

(A).   (B).   (C).

(D).   (E).   (F).

FIGURE 1. Laboratory Equipment and Experimental Activities (a, b) Avery Dension Universal Testing Machine (c) Material Measurement using Weighing Machine (d) Slump Test (e) Casting of Concrete Cubes (f) Concrete Cubes Immersed in Potable Water Curing.

Interpolating in the y-direction to obtain the desired estimate:

$$f_{x,y} = \frac{y_2 - y}{y_2 - y_1} f(x, y_1) + \frac{y - y_1}{y_2 - y_1} f(x, y_2) \quad (3)$$

Comparisons of the predicted results obtained from the use of the bilinear interpolation method was made with the observed experimental results at unique check points using a simple percentage difference formula;

$$\text{Per.Diff.} = \frac{actual\ result - model\ result}{actual\ result} \cdot 100\,\%.$$

3. Results and discussion

3.1. Chemical analysis of pulverized coconut shell, periwinkle shell and palm kernel

The chemical analysis of the PCS, PPS and PPKS was carried out and the chemical compositions determined. The results are shown in Table 1.

The physical observation shows that the samples are different in colour (brown) when compared to cement (light grey), which does not translate to the ability to perform alike, but their individual performance is based on the degree of constituents' chemical elements present in them. It was observed that the combined percentage masses of silica (SiO_2), alumina (Al_2O_3) and ferric oxides (Fe_2O_3) for the samples were lower than the various class type of pozzolans according to ASTM C618-12a [36]. CaO, known for providing strength in cement, was observed to be very low in the samples.

This can be attributed to the low strength performance and increase in setting time. The absence of SiO_2 and Al_2O_3 in the samples would have an adverse effect on the strength and setting property of the cement paste binding the aggregates together.

The MgO was found to be within the lower limit range of less for cement, PPS and PPKS but the PCS sample recorded higher value which can be attributed to the reduction of strength of concrete [28, 36]. The percentages of Na2O and K2O known as the alkali oxides in the samples were observed to be large when compared to the standard range [36]. This resulted
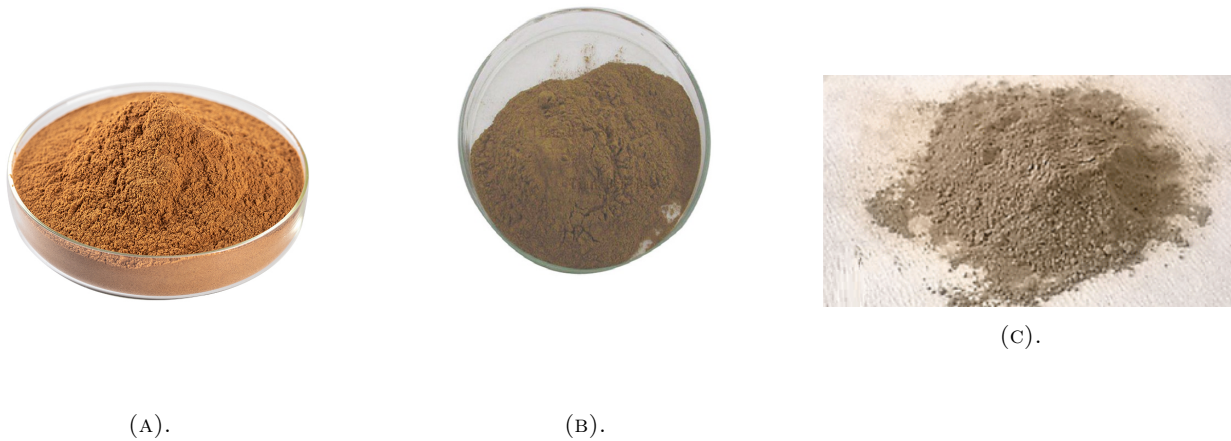
(A).

(B).

(C).

FIGURE 2. Supplementary Cementitious Materials (SCM) (a) Pulverized Coconut Shell (b) Pulverized Palm Kernel Shell (c) Pulverized Periwinkle Shell.

Parameters	Cement	Pulverized Coconut Shell (%)	Pulverized Periwinkle Shell (%)	Pulverized Palm Kernel Shell (%)
Calcium Oxide (CaO)	63.97	8.918	10.84	9.68
Silica (SiO_2)	18.34	27.57	22.32	20.28
Aluminium Oxide (Al_2O_3)	4.73	14.38	9.37	3.38
Ferric Oxide(Fe_2O_3)	0.38	5.82	6.89	7.42
Potassium Oxide (K_2O)	0.48	6.981	4.98	6.81
Magnesium Oxide (MgO)	2.16	3.196	2.49	2.89
Sodium Oxide (Na_2O)	0.55	5.189	6.12	5.81
Chlorine (Cl)	1.83	6.28	7.62	6.58
Sulphate (SO_4^{2-})	0.51	8.00	7.40	7.60

TABLE 1. Chemical Composition of Supplementary Cementitious Materials (SCM) and Cement.

in some difficulties in regulating the setting time of the cement paste.

3.2. PHYSICAL PROPERTIES AND SIEVE ANALYSIS

Results of the physical properties tests on the concrete constituent used in this study are presented in Table 2.

According to Unified soil classification system [37, 38], the coarse aggregate is classified as poorly graded granite because its coefficient of uniformity ($C_u = D_{60}/D_{10}$) value is less than 4 and Coefficient of Curvature ($C_c = (D_{30} \times D_{30})/(D_{60} \times D_{10})$)value is between 1-3 as presented in Figure 3. Also, the fine aggregate is classified as poorly graded sand because its C_u value is less than 6 and its C_c value is between 1-3 [37, 38].

The densities and specific gravity of the concrete constituents used met the specified standards of Specific Gravity (2.4-2.9), Bulk Density for the aggregates are classified as normal weight aggregate according American Standard Test Method [39]. The aggregate crushing and impact values of 22.01 and 13.26 respectively were in an accordance with the relevant standards [40].

3.3. EFFECT OF POZZOLANS ON THE SETTING TIMES OF CEMENT

The results of the setting time tests of cement paste having pozzolans incorporated at various replacement levels are presented in the figures below.

It was observed that the initial setting times of cement and pozzolans are higher than the specified standard of 45 minutes but their final setting time recorded a lower time, which is within the specified standard of 600 minutes [41]. From figures 4a and 4b, it was observed that both the initial and final setting times of the paste incorporated with pozzolans increased as the replacement level of the pozzolans increased.

Specifically, the addition of each of the three materials to cement paste respectively caused a retardation of the setting time. The blended cement with pulverized coconut shell (PSC) had the highest initial and final setting times when compared to others. In order words, these pozzolans are acting as a retarder and could be considered good for temperate regions, or in ready- mix concrete transported over a long distance. This behaviour may be attributed to the reduction of the strength forming compounds (C3S and C3A) in the blended cement through the partial replacement of cement with pozzolans. These compounds are re-

Parameters	Granite	Sand	Cement	PCS	PPS	PPKS
Coefficient of uniformity (C_u)	1.58	3.03	-	-	-	-
Coefficient of Curvature (C_c)	1.03	1.08	-	-	-	-
Fineness modulus	3.88	4.49	4.25			
Dry Density (kg/m^3)	1403.29	1405.01	-	-	-	-
Bulk Density (kg/m^3)	1407.36	1409.55	1297	1312	1320	1384
Specific Gravity	2.66	2.63	2.75	2.40	2.46	2.64
Moisture Content (%)	0.29	0.6	-	1.45	1.23	1.34
Aggregate Crushing Value (%)	22.01	-	-	-	-	-
Aggregate Impact Value (%)	13.26	-	-	-	-	-

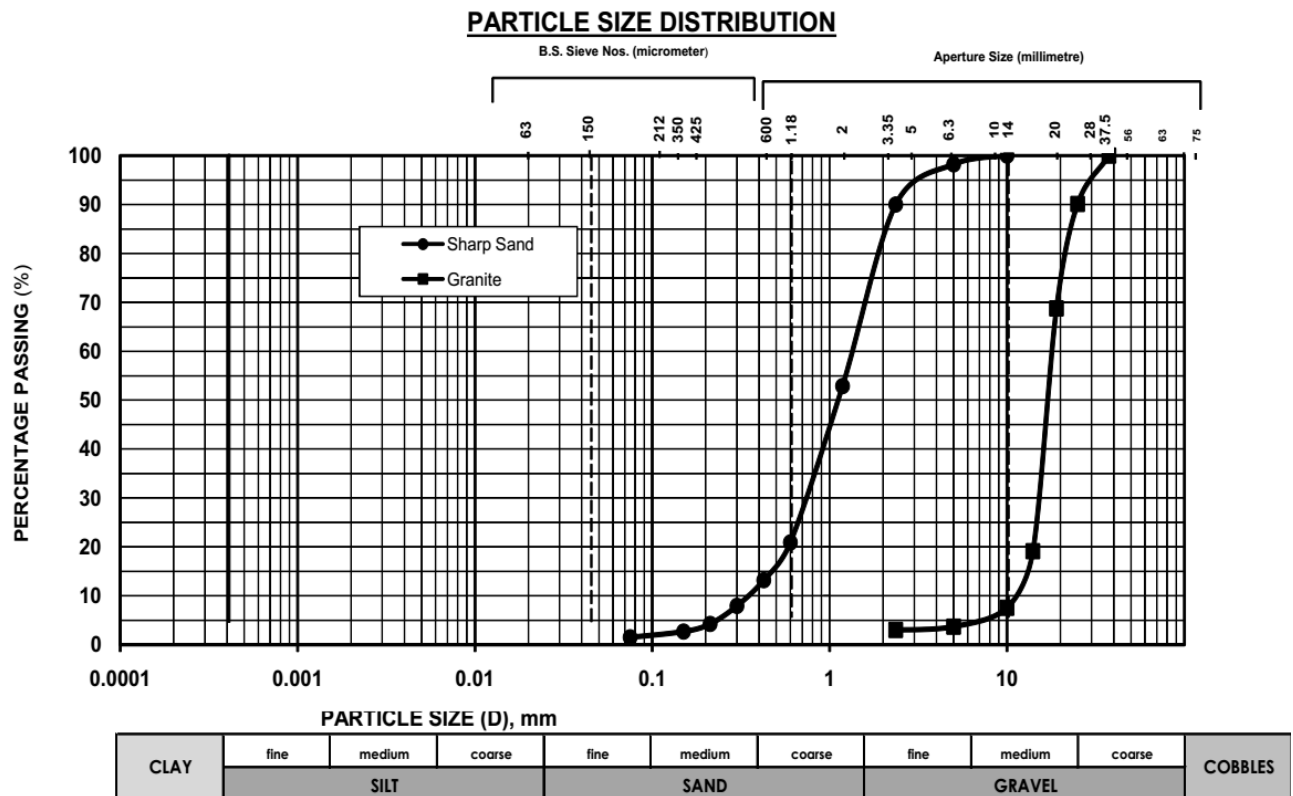TABLE 2. Physical Properties of Concrete Constituents.

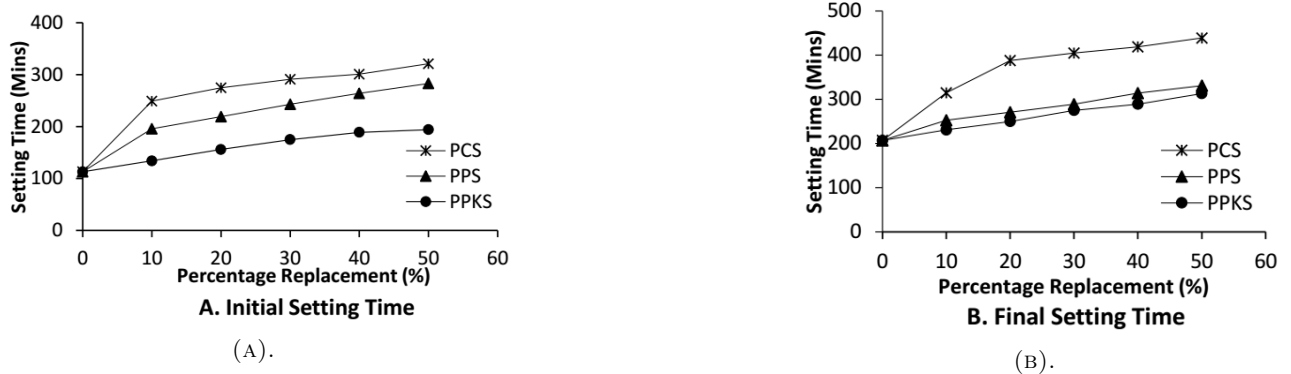FIGURE 3. Particle Size Distribution for Aggregates.

FIGURE 4. Effect of Pozzolans on the Setting Time of Cement Paste.

sponsible for the early strength gain and the initial and final setting times of cement.

3.4. Effect of PCS, PPS and PPKS on the workability of concrete

The variations in the workability of pozzolan blended concrete were determined using slump test and the results revealed a high degree of workability for the PPS and PPKS from control to a 20 % replacement level while the PCS exhibit a high workability for control and at a 10 % replacement level. A further increase in replacement levels for the PCS, PPS and PPKS resulted to a low degree of workability.

Figure 5 shows the variations of the slump value of the PCS, PPS and PPKS blended concretes. The values were taken at different replacement levels. As depicted in the figure, the workability decreased as the replacement level of different pozzolans increased. The trends observed in the slump values can be attributed to the high moisture absorption capacity of the pozzolan particles in the mix as the percentage replacement increased, thus transiting from plastic mix to stiff-plastic mix. Pulverized palm kernel shell was observed to have higher slump values when compared to the other pozzolans.

3.5. Effects of PCS, PPS and PPKS on the density of concrete

The density of the concretes produced with different pozzolans incorporated into the concrete matrix generally increased as the curing age increased. This could be attributed to the adequate amount of moisture available for continuous hydration and volume stability.

Figure 6a shows the variation of the percentage replacement of three pozzolans (PCS, PPS & PPKS) on the density of concrete at 7 days curing age. As depicted in the figure, the density of pulverized coconut shell blended concrete decreased as the replacement level increased while the densities of pulverized periwinkle shell blended concrete and pulverized palm kernel shell blended concrete increased for values up to a 30 % replacement level and further replacement levels led to a decrease. Figure 6b shows the effect of different pozzolans (PCS, PPS & PPKS) on the density of concrete at 28 days curing age. Similar trends were observed for the 7 days curing age when the increase in the replacement of the PCS led to the decrease in density while the increase in the PPS and PPKS resulted in an increase in the density for values up to a 30 % replacement level and subsequent increase gave a decrease in density.

From these figures, the trends observed can be attributed to the quantity of Magnesia or Magnesium oxide present in the concrete matrix. The decrease in the densities of pulverized coconut shell blended concrete can be ascribed to the high quantity of 3.198 % Magnesia above the specified range of o.1 to 3 % which could impart its hardness. Also, when the quantity

of the Magnesia in the concrete matrix becomes more than the allowable, it could result in a decrease in the density of concrete as observed in pulverized periwinkle shell and palm kernel shell blended concretes.

3.6. Effects of PCS, PPS and PPKS on compressive strength of concrete

The variation in the compressive strength of pozzolan blended concretes at different curing ages are presented in Figure 7. It was observed that the compressive strength increased with an increase in curing age. The reason for such behaviour is that the concrete specimens are exposed to an environment that facilitates continuous hydration with resultant strength gains. Also, the curing condition helped in the prevention of moisture loss needed for the continuous hydration.

Figures 7a and 7b illustrate the outcome of having some pozzolans incorporated in concrete at varied curing age. From the figures, it is observed that the compressive strength gradually decreased as the percentage replacement increased from 0 % to 50 % at 10 % intervals for the three pozzolans. However, pulverized coconut shell is observed to yield the lowest compressive strength as its replacement level increased while pulverized periwinkle shell recorded the highest values of compressive strength when compared to the other two pozzolans. The decline in the compressive strength for the three pozzolans can be attributed to the lack of adhesion between the pozzolans and cement paste leading to losses in stability and surface area. Also, the breakdown of the internal structure in the bond strength between the cement-pozzolans paste and aggregates resulted in reduced compressive strength. The compressive strength at 28 days curing age decreased by 13.38 %, 10.50 % and 16.50 % at 10 % replacement level, 23.98 %, 16.88 % and 23.93 % at 20 % replacement level, 36.21 %, 27.53 % and 32.95 % at 30 % replacement level, 45.47 %, 39.23 % and 45.00 % at 40 % replacement level, 71.27 %, 52.23 % and 70.07 % at 50 % replacement level for PCS, PPS and PPKS respectively. The values of compressive strength for the three pozzolans are above $17 \, \text{N/mm}^2$ at the 10 % replacement level. This indicates that the PCS, PPS and PPKS at 10 % replacement level are suitable for the production of pozzolan blended concretes for structural works using a water-binder ratio of 0.6.

3.7. Strength activity index (SAI) on pozzolans blended concrete

The strength activity index (SAI) measures the pozzolanicity of cement replacement materials (CRMs) and the measure is based on the variation of the strength with respect to its control in percent. According to ASTM [4], a CRM can be classified as a pozzolan if the strength of the blended cement at 7-day and/or 28-day is not be less than 75 % of the strength of normal concrete. The strength activity
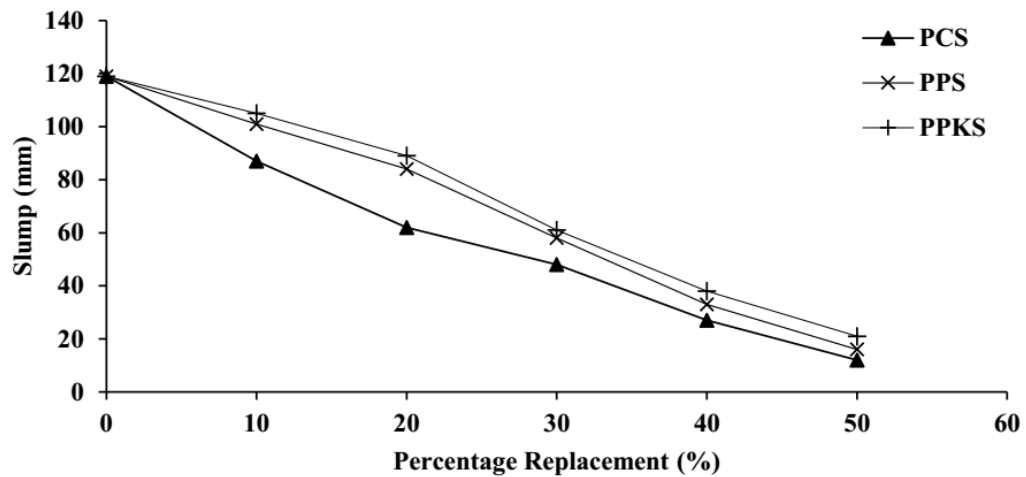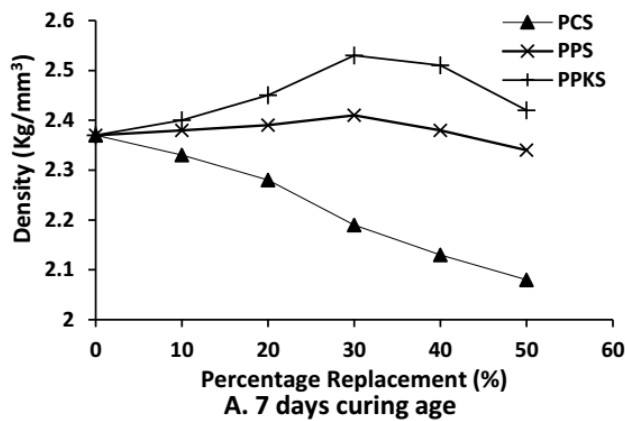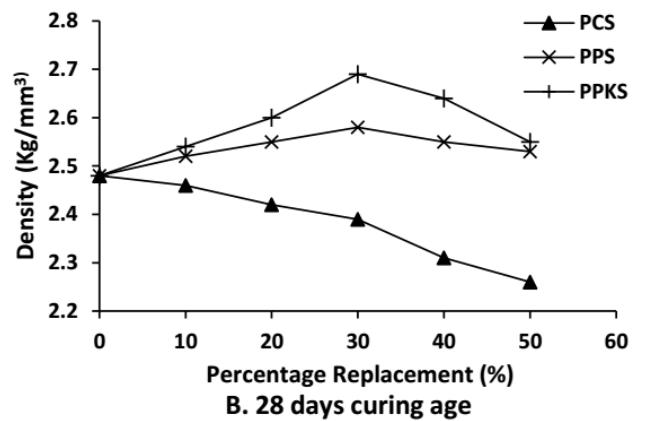
FIGURE 5. Slump Values of Pozzolans Blended Concrete in Fresh Mix Stage.

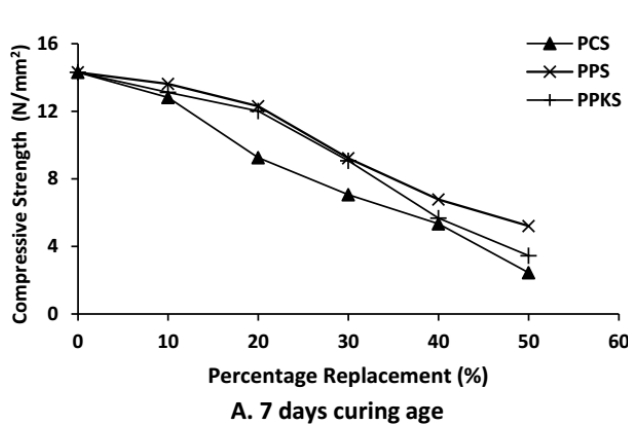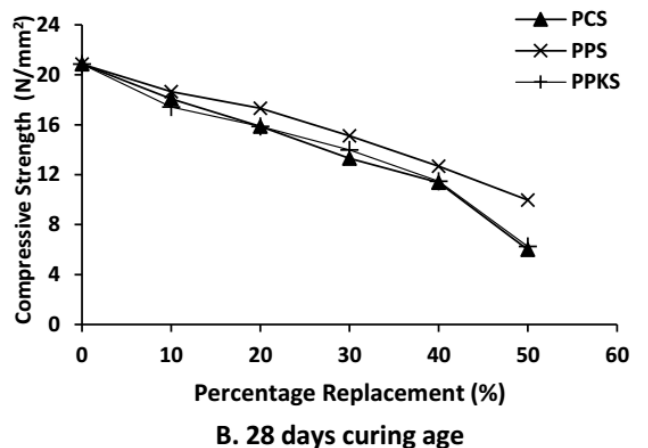(A).   (B).

FIGURE 6. Densities of Pozzolans Blended Concrete at 7 days and 28 days Curing Ages.

(A).   (B).

FIGURE 7. Compressive Strength of Pozzolans Blended Concrete at 7 and 28 days curing ages.

Curing Age	Percentage Replacement (%)	PCS		PPS		PPKS	
		CS (N/mm^2)	SAI (%)	CS (N/mm^2)	SAI (%)	CS (N/mm^2)	SAI (%)
7 Days	0	14.3	100	14.3	100	14.3	100
	10	12.81	89.58	13.62	95.25	13.11	91.68
	20	9.26	64.76	12.3	86.01	12.01	83.99
	30	7.06	49.37	9.22	64.48	9.07	63.43
	40	5.34	37.34	6.78	47.41	5.67	39.66
	50	2.44	17.06	5.21	36.43	3.45	24.13
28 Days	0	20.85	100	20.85	100	20.85	100
	10	18.06	86.62	18.66	89.50	17.41	83.50
	20	15.85	76.02	17.33	83.12	15.86	76.07
	30	13.3	63.79	15.11	72.47	13.98	67.05
	40	11.37	54.53	12.67	60.77	11.47	55.01
	50	5.99	28.73	9.96	47.77	6.24	29.93

TABLE 3. Strength Activity Index of PCS, PPS and PPKS.

index for the pozzolan blended concretes are is presented in Table 3. From Table 3, at 7-day, the three pozzolans met the specification for the 10 % replacement, and but at the 20 % replacement level, two pozzolans (PPS & PPKS) met the minimum permissible level of 75 % of their control strength. At 28 days curing age, the maximum SAIs for 10 % to 50 % are 86.62 %, 89.50 % and 83.50 % for 10 % replacement level, 76.02 %, 83.11 % and 76.07 % for 20 % replacement level, 63.79 %, 72.47 % and 67.05 % for 30 % replacement level, 54.53 %, 60.77 % and 55.01 % for 40 % replacement level, 28.73 %, 47.77 % and 29.93 % for 50 % replacement level. This implies that up to 20 % replacement could be adopted as an optimum replacement level of cement with pulverized coconut shell, periwinkle shell and/or palm kernel shell for normal concrete production.

3.8. EFFECT OF PCS, PPS AND PKS ON TENSILE STRENGTH OF CONCRETE

The experimental results of the tensile strength of the investigated pozzolan blended concretes are presented in figures 8a and 8b. The tensile strength increased significantly as the curing ages increased from 7 days to 28 days. Figure 8 shows the test results of the PCS, PPS and PPKS blended concretes varied from control (0 %) to the 50 % replacement level at an interval of 10 % for 7- and 28- days of water curing. From these figures, it is observed that the use of these pozzolans as a cement replacement resulted in a decline in the tensile strength of the concretes. The increase in the replacement level of cement in the concrete matrix resulted to in an increase in the reduction of tensile strength to 19.08 %, 25.77 %, 44.79 %, 48.47 % and 67.49 % for PCS, 16.33 %, 18.84 %, 37.27 %, 42.57 % and 45.93 % for PPS, 21.93 %, 25.72 %, 41.96 %, 48.01 % and 58.90 % for PPKS when compared with the control mix at 28 days. Also, it was observed that the tensile

strength for the pozzolans blended concrete varies between 1/8 to 1/12 of their compressive strength.

3.9. MATHEMATICAL MODEL TO PREDICT COMPRESSIVE STRENGTH OF POZZOLANS BLENDED CONCRETE PROPERTIES

Predictive models were developed using Bilinear Interpolation Method for two inputs and one output system; having the two inputs as being the curing age and percentage replacement for the different pozzolans. The mathematical models developed are presented below;

For the compressive strength of pulverized coconut shell;

$$f_{cu} = -2.558333359 \times 10^{-7}R^5-$$
$$- 0.00001083332963R^4 + 0.002996249948R^3-$$
$$-0.00022837706C^3+12.91000000+0.012408169C^2-$$
$$- 0.1152666679R^2 + 2.275672175 \times 10^{-10}R^5C^3-$$
$$-1.222789117\times10^{-8}R^5C^2+1.525396828\times10^{-7}R^5C-$$
$$-1.988176304\times10^{-8}R^4C^3+1.071003446\times10^{-6}R^4C^2-$$
$$-0.00001167758013R^4C+4.02089414\times10^{-7}R^3C^3-$$
$$- 0.2134353783 \times 10^{-3}R^3C^2+$$
$$+ 0.4369424621 \times 10^{-4}R^3C+$$
$$+3.39731152 \times 10^{-6}R^2C^3 - 0.0002122023963R^2C^2+$$
$$+ 0.00899871059R^2C - 0.0000978781988RC^3+$$
$$+ 0.00574642857RC^2 - 0.1369956349RC+$$
$$+ 0.125476196C + 0.9554333322R \quad (4)$$

For the compressive strength of pulverized periwinkle shell;

$$f_{cu} = -8.749999850 \times 10^{-7}R^5+$$
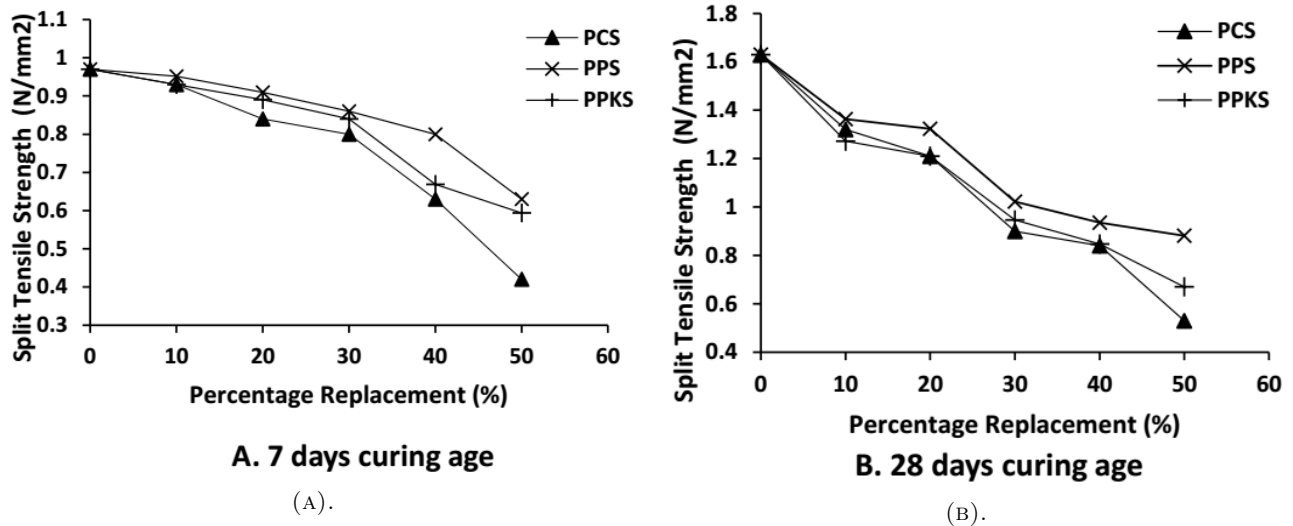$$+ 0.0001254166631R^4 - 0.006229166683R^3-$$
$$-0.00022837706C^3+12.91000000+0.012408169C^2+$$

FIGURE 8. Split Tensile Strength of Pozzolans Blended Concrete at 7- and 28-days Curing ages.

$$+ 0.1228083290R^2 - 3.753644352 \times 10^{-10}R^5C^3 +$$
$$+ 1.145408186 \times 10^{-8}R^5C^2 - 4.52381311 \times 10^{-9}R^5C +$$
$$+ 4.047214231 \times 10^{-8}R^4C^3 - 1.137329988 \times 10^{-6}R^4C^2 -$$
$$- 3.069443624 \times 10^{-6}R^4C - 1.341715255 \times 10^{-6}R^3C^3 +$$
$$+ 0.00003064200662R^3C^2 + 0.0003516666700R^3C +$$
$$+ 0.00001091877345R^2C^3 + 0.0000203655832R^2C^2 -$$
$$- 0.01218710214R^2C + 0.0000971088407RC^3 -$$
$$- 0.007122618889RC^2 + 0.1413428547RC +$$
$$+ 0.125476196C - 0.9488333240R \quad (5)$$

For the compressive strength of pulverized palm kernel shell;

$$f_{cu} = -3.56250000 \times 10^{-6}R^5 +$$
$$+ 0.0004691666657R^4 - 0.02144708339R^3 -$$
$$- 0.00022837706C^3 + 12.91000000 +$$
$$+ 0.012408169C^2 + 0.3921833343R^2 +$$
$$+ 7.871720176 \times 10^{-10}R^5C^3 -$$
$$- 4.452380980 \times 10^{-8}R^5C^2 +$$
$$+ 7.457142890 \times 10^{-7}R^5C - 1.018788466 \times 10^{-7}R^4C^3 +$$
$$+ 5.758928567 \times 10^{-6}R^4C^2 - 0.00009674305549R^4C +$$
$$+ 4.616942050 \times 10^{-6}R^3C^3 -$$
$$- 0.2604336751 \times 10^{-3}R^3C^2 +$$
$$+ 0.4369424621 \times 10^{-2}R^3C -$$
$$- 0.8636216480 \times 10^{-4}R^2C^3 -$$
$$+ 0.004841454123R^2C^2 - 0.08025902824R^2C +$$
$$+ 0.0005877713022RC^3 - 0.03239914980RC^2 +$$
$$+ 0.5147194461RC + 0.125476196C -$$
$$- 2.548666671R \quad (6)$$

Where: R - Percentage Replacement Level and C - Curing Age.

Table 4 shows the comparison of the results of experimental findings and bilinear interpolation models. From the percentage difference calculated for each replacement level for all the pozzolans, it was observed that the values of the mathematical models are in good agreements with the experimental results.

The two-way statistical analysis of variance (ANOVA) without replication on the 7, 14, 21 and 28-day compressive strength results at 95 % confidence level (that is $\infty = 5$) is presented in table 5. The percentage replacements level and curing age were considered as the source of variations of the compressive strength.

From Table 5 the p-values for the rows and columns of the PCS, PPS and PPKS are less than 0.05 and F is greater than F-crit, we reject the null hypothesis, and so at the 95 % level of confidence we conclude that the curing age and the percentage replacement have a significant effect on the compressive strength of concrete.

4. CONCLUSIONS

From research carried out, the following conclusions can be made:

(1.) The quality of the PCS, PPS and PPKS materials were below the limits of Class F, C and N pozzolanic materials according to ASTM C 618.

(2.) The addition of the PCS, PPS and PPKS to the cement paste matrix resulted in an increase in the setting. This indicates that the three pozzolans are good retarders, hence they can be used for a construction where an early setting of concrete is not required such as plastering of walls.

(3.) The workability of the pozzolans blended concrete decrease with an increase in the pozzolans replacement level. This resulted in stiff mixes.

Curing Age	Per. Rep.(%)	PCS	Model	Per. Diff.	PPS	Model	Per. Diff.	PPKS	Model	Per. Diff.
7 Days	0	14.3	14.300	-4.895E-07	14.3	14.300	-4.9E-07	14.3	14.300	-4.9E-07
	10	12.81	12.810	-3.123E-07	13.62	13.620	-5.9E-07	13.11	13.110	-2.3E-07
	20	9.26	9.259	3.24E-07	12.3	12.300	-6.5E-07	12.01	12.009	2.16E-06
	30	7.06	7.059	1.261E-06	9.22	9.220	-5.6E-07	9.07	9.069	6.63E-06
	40	5.34	5.339	5E-06	6.78	6.779	5.32E-06	5.67	5.669	6.48E-05
	50	2.44	2.439	1.643E-05	5.21	5.209	4.07E-05	3.45	3.449	0.000137
28 Days	0	20.85	20.850	-3.453E-06	20.85	20.850	-3.5E-06	20.85	20.850	-3.5E-06
	10	18.06	18.060	-3.433E-06	18.66	18.660	-4.1E-06	17.41	17.410	-4.6E-06
	20	15.85	15.850	-2.082E-06	17.33	17.3300	-4.7E-06	15.86	15.860	-1.3E-06
	30	13.3	13.299	3.158E-06	15.11	15.110	-6.3E-06	13.98	13.980	-2E-05
	40	11.37	11.369	1.706E-05	12.67	12.670	-8.7E-07	11.47	11.469	8.55E-05
	50	5.99	5.989	8.681E-05	9.96	9.959	4.69E-05	6.24	6.240	-2.7E-05

Table 4. Validation of Developed Model for Compressive Strength (N/mm2) of Pozzolans (PCS, PPS and PPKS) Blended Concretes.

ANOVA FOR PCS						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	459.2312	5	91.84623	305.9878	1.54E-14	2.901295
Columns	109.5279	3	36.50929	121.6315	9.47E-11	3.287382
Error	4.502446	15	0.300163			
Total	573.2615	23				

ANOVA FOR PPS						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	286.7838	5	57.35675	339.8477	7.06E-15	2.901295
Columns	103.4237	3	34.47458	204.2673	2.2E-12	3.287382
Error	2.531579	15	0.168772			
Total	392.7391	23				

ANOVA FOR PPKS						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	431.5447	5	86.30893	235.6973	1.06E-13	2.901295
Columns	72.07297	3	24.02432	65.60696	7.46E-09	3.287382
Error	5.492783	15	0.366186			
Total	509.1104	23				

Table 5. Results of Two-way Analysis of Variance for Compressive Strength (N/mm^2) of Pozzolans (PCS, PPS and PPKS) Blended Concretes.

(4.) The density of pulverized coconut shell (PCS) blended concrete decreased as the replacement level increased while the densities of pulverized periwinkle shell (PPS) blended concrete and pulverized palm kernel shell (PPKS) blended concrete increased for values of up to 30 % replacement level and further replacement levels led to a decrease.

(5.) The compressive strength and tensile strength declined as the percentage replacement increased from 0 % to 50 % at 10 % intervals for the three pozzolans. The values of compressive strength for the three pozzolans are above $17\,\mathrm{N/mm^2}$ at the 10 % replacement level; an indication that the PCS, PPS and PPKS at the 10 % replacement level are suitable for the production of pozzolans blended concrete for structural works using a water-binder ratio of 0.6.

(6.) At 28 days curing age, the strength activity index for the pozzolans blended concretes was more than 75 % of the strength of normal concrete at the 20 % replacement level. The tensile strength for the pozzolans blended concretes varied between 1/8 to 1/12 of their compressive strength.

(7.) The models developed using the bilinear interpolation method for the compressive strengths of the PCS, PPS, and PPKS blended concrete are in a good agreement with the experimental results. The statistical analysis of the variance showed that the replacement level of the PCS, PPS, and PPKS contents and curing age have effect on the compressive strength of concrete.

Acknowledgements

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