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Structural Strength Characteristics of Cement-Cassava Peel Ash Blended Concrete

Musbau Ajibade Salau
Department of Civil and Environmental Engineering, University of Lagos, Akoka, Lagos, Nigeria
Tel: +234-80-33303420 E-mail: ajibsalau@yahoo.co.uk

Efe Ewaen Ikponmwosa (Corresponding Author)
Department of Civil and Environmental Engineering, University of Lagos
Akoka, Lagos, Nigeria
Tel: +234-80-54897732 E-mail: efe_ewaen@yahoo.com , eikponmwosa@unilag.edu.ng

Kolawole Adisa Olonode
Department of Civil Engineering, Obafemi Awolowo University
Ile-Ife, Nigeria
Tel: +234-70-36439726 E-mail: makkolawole@yahoo.com

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Abstract

This study focuses on structural strength characteristics of cement-CPA blended concrete. Cement was replaced partially by CPA between 5 and 25% by weight of cement at 5% interval. Water binder ratios (w/b) of 0.5, 0.55, 0.6, 0.65 and 0.7 were used to produce the blended concrete of mix 1:2:4. The results of the investigation indicated that as the replacement of CPA increases, more water was required to make the blended concrete workable, hence, w/b of 0.7 was found to be optimum to produce workable blended concrete. The compressive strength of the blended concrete increases with age and reduces with increase in CPA content but at 5, 10 and 15% CPA the strength activity indices (SAIs) are 83, 82 and 79% at 28-day while at 120-day strength SAIs are 99, 95 and 87% showing that CPA contributes to later strength development than early strength development, a property that is peculiar to pozzolanic materials. Also, these values were greater than 75% specified by ASTM C311-98 showing that up to 15% is adequate. Similar trend was observed for flexural strength development as flexural crack was independent of the CPA content in the blended concrete. The results further show that CPA does not have appreciable influence on the density of the blended concrete. Regression analysis was conducted on the data and models showing relationship between compressive strength and curing ages for up to 15% CPA are proposed

Keywords: Cassava peel ash, cement, pozzolan, workability, compressive strength and flexural strength

1. Introduction

The use of pozzolanic materials is found in many ancient civilizations. Pozzolans were used to improve the properties of lime, and many structures are still extant as a testament to the durability of lime– pozzolan mortars and concrete (Caijun, 2001). More recently, in Europe and the USA, there have been numerous high rise buildings, highways, dams, bridges, harbours, canals, aqueducts and sewer systems built with the use of pozzolan-cement mixtures (Wilson and Ding, 2007).

Frías et al (2007), Cizer et al.(2006) and Ketkukah and Ndububa (2006) are some of the notable researchers who have demostrated the use of ashes of rice husk, sugar cane straw and groundnut husk as pozzolan in concrete. They have shown that compressive strength of concrete incorporating these ashes increases while the workability is enhanced. In the works of Chindaprasirt et al. (2007) and Coutinho (2002), the use of rice husk ash reduces the effects of alkali-silica reactivity as well as drying shrinkage. Nehdi et. al (2003) and Mehta and Monteiro (2004) reported that the performance of these materials, as pozzolans, depends on the type and amount of amorphous silica content they contain which further depend on duration and calcination temperature. Ramezanianpour et al. (2009) suggested burning temperature of 650^0C for 60 minutes in the case of rice husk ash while between 800^oC and 1000^0C was used for sugar cane straw ash (Moisés et. al, 2007)

Cassava peel (CP) is a by-product of cassava processing, either for domestic consumption or industrial uses. Adesanya et al (2008) reported that cassava peel constitutes between 20-35% of the weight of tuber, especially in the case of hand peeling. Based on 20% estimate, about 6.8 million tonnes of cassava peel is generated annually and 12 million tonnes is expected to be produced in the year 2020. Indiscriminate disposal of cassava peels due to gross under utilization as well as lack of appropriate technology to recycle them is a major challenge, which results in environmental problem. Thus, there is need to search for alternative methods to recycle them (cassava peels).

Salau and Olonade (2011) studied the pozzolanic potential of cassava peel ash (CPA) and their results showed that cassava peel ash possesses pozzolanic reactivity when it is calcined at 700^0C for 90 minutes. At these conditions, CPA contained more than 70 per cent of combined silica, alumina and ferric oxide.

This work studies workability, compressive and flexural strengths of concrete with cassava peel ash used as partial substitute for cement.

2. Materials and Methodology

2.1. Materials

Cassava peels were collected from cassava peels dump site at different *fufu* processing centres in Ilaro, Ogun State, Nigeria. The ash was produced by calcination for 90 minutes at 700^oC. It was sieved, using 150 μm sieve size to produce fine ash. The chemical composition and physical characteristics of the ash are presented in Table 1. The cement used in this study was Ordinary Portland Cement with brand name *Burham.* Its chemical composition was determined using X-ray florescence technique at Lafarge/WAPCO Cement Company. The properties of the cement are presented in Table 1. Fine aggregate used was river sand while crushed granite of maximum nominal particle size of 19 mm was used as coarse aggregate. The grading for the aggregates was done according to BS 1377 Parts 1 and 2. The uniformity coefficient (*Cu*) for the sand and granite were 5.4 and 5 respectively while their coefficients of curvature (*Cc*) were 1.36 and 1.0 respectively. Potable water was used in producing the concrete mixture.

2.2 Mix Proportion and Sample Preparation

The concrete investigated was of mix ratio 1:2:4 (cement and cassava peel ash: sand: granite) with varied water/binder ratios of 0.55, 0.60, 0.65 and 0.70. The cement was replaced with cassava peel ash at 0%, 5%, 10%, 15%, 20% and 25% by weight of cement as binder and mixed with sand and granite as fine and coarse aggregates respectively. Batching of the concrete mix was by weight.

2.3 *Testing Procedures*

In order to determine optimum water binder ratio that could produce workable blended concrete, slump and compacting factor (CF) tests were conducted in accordance with BS 1881(102) and BS 1881(103) while the density was determined by following the procedures specified in BS1881 (107).

Concrete cubes of sizes 150x150x150 mm were prepared using predetermined constant optimum water binder ratio (w/b) of 0.70 with different percentages of cassava peel ash as substitute of cement. 3 No cubes for each concrete mix were cast and cured for 7, 28, 56, 90 and 120 days. Prior to crushing, the specimens were removed at each curing age, weighed and were later tested using compression machine. Average of three readings was determined and noted.

Concrete beams of sizes 150x150x760 mm were cast and cured for 7, 28, 56, 90 and 120 days. At testing day, the beams were marked indicating the supports and loading positions. The experimental set-up is shown in Figure 1.

The procedures described in ASTM C78 were adopted. Flexural strengths for each of the beam specimens were determined using relationship recommended by ASTM C78. This is expressed in terms of Modulus of Rupture (MR). Average of three readings was recorded. The progression of flexural cracking as the bending moment on a concrete beam is increased was monitored.

3. Results and Discussion

3.1 Effect of Water-Binder Ratio on Workability of CCPA Blended Concrete

3.1.1 Slump Test

The results of the slump carried out on concrete with varying percentage of cassava peel ash (CPA) as replacement for cement at different water-binder ratio are presented in Table 2. The results show that for all mixes, the slump type was 'true slump' except for mixes containing more than 15% CPA at 0.55 and 0.60 water-binder (w/b) ratios, where the mixtures were very viscous and stiff due to inadequacy of water. As the w/b ratio increases from 0.55 to 0.70 at an interval of 0.05, the slump increases accordingly for equal percentage of CPA in the mix. For example, at 5% CPA the slump increases from 24 mm to 70 mm. However, the slump decreases with increase in amount of CPA for the same water-binder ratio. This indicates that more water is required to maintain the same consistency as the CPA content increases (Figure 2). At water binder ratio of 0.55 with 0%, 5% and 10% CPA content, the slump values were 31, 24 and 15 mm respectively and the slumps were 'true'. But at 15%, the mix became harsh with zero slumps at 0.55 and 0.60 of w/b. No workable mix could be achieved with CPA content above 15%. It is due to the fact the water was inadequate to achieve homogeneous concrete mix. This shows that cassava peel ash has potential to absorb more water than ordinary Portland cement in the mix. Nevertheless, water-binder ratio of 0.65 and 0.70 were adequate to produce workable mix with true slump for all the percentages of CPA used for the mixes.

The recent European standard states that the slump test is sensitive to changes in consistency corresponding to slumps between 10 and 200 mm and the test is not considered suitable beyond these extremes (Domon, 2003). Also, mix having slump between 60-130 mm is considered being plastic and required either mechanical or hand compaction. This suggests that 0.65 and 0.70 water binder ratios (w/b) could be considered. In order to avoid being on the lower extreme of 10 mm (slump value for 25% CPA at 0.65 water-binder ratio), water binder ratio of 0.70 should be considered suitable.

3.1.2 Compacting Factor Test

The results of the compacting factor test conducted on samples of cement-CPA blended concrete at various water-binder ratios are also shown in Table 2. It is observed that compacting factor (CF) of mixes containing 20% and 25% CPA at 0.55 and 0.6 water-binder ratios could not be determined because the mixes were too stiff due to inadequate water to achieve workable mix. The same stiff mix obtained is responsible for non-availability of compacting factor value for 15% CPA replacement level at 0.55 ratio. For ratios 0.65 and 0.7, the CF increases with increase in water content but decreases as the content of CPA increases except for 0.70 where CF (0.915) was constant for CPA content between 0 to 10 % CPA. This then increases up to 0.925 at 25%. This indicates that mix with 0.65 and 0.7 w/b ratio can easily compact on placement under gravity. According to BS 1881 103, the compacting factor lies between 0.8 and 0.92 for normal range of concrete.

Compacting Factor measures the effect of a standard amount of work (height of fall) on compaction, hence, requires adequate water content to achieve relatively full compaction. This is true in the case of water-binder ratios of 0.65 and 0.70 for all the mixes. But, the CFs for w/b of 0.70 for all values of CPA was higher (Table 2). Thus, 0.70 water-binder ratio can be considered as optimum.

3.2 Density of Cement-CPA Blended Concrete

Table 3 summarizes the densities of concrete made with 0 to 25% at interval of 5% replacement of cement with CPA. The results show that the densities range between 2414 and 2473 Kg/m^3 indicating that they can be categorized as normal concrete with density of 2400 Kg/m^3. It is observed that the percentage replacement level of cement with CPA did not have any appreciable influence on the densities of the test specimens of the blended concrete. This may be attributed to the lower specific gravity of the CPA which was much lower than that of cement (Table 1). This further shows that the concrete density does not solely depends on the binder content but is mainly depends on the amount and density of the aggregate, how much air is entrapped or purposely entrained, and the aggregate size.

3.3 Compressive Strength

The compressive strength of cement-CPA blended concrete, irrespective of the amount of CPA in the mixture, increases as the age of curing increases. However, the compressive strength decreases as CPA content increases. This is more pronounced at the early age especially at age 7 days (Figure 3). For normal concrete, 0% CPA, the compressive strength at 28-day is 18.7 N/mm^2 while that of 5, 10, and 15% are 15.6, 15.3 and 14.7 N/mm^2 respectively representing decrease of 16.5, 18.2 and 21.4% respectively. For the same day, 12.8 and 12.5 N/mm^2 are strength for concrete containing 20 and 25% CPA respectively. But at later age, 90 days and 120 days, the strength development is observed to be on the increase with concrete containing CPA compared to the normal concrete. At 120-day, normal concrete has strength of 22.3 N/mm^2 which is about 16.1% higher than 28-day strength. Nevertheless, concrete with 5, 10 and 15% have strength of 22.2 N/mm^2 (29.7% increase), 21.2 N/mm^2 (27.8%) and 19.4 N/mm^2 (24.2%) respectively while 20 and 25% CPA concrete have strength of 26.6 N/mm^2 and 16.2 N/mm^2 respectively with the same strength increase of 22.8% each (Table 3).

With the exception of 20 and 25% CPA replacement of cement, it can be observed that the difference in strength between the normal concrete and CPA blended concrete reduces progressively with age with 5, 10 and 15% CPA replacement levels at 120-day (Table 3 and Figure 3). This also indicates that CPA has potential to contribute to late strength development when not more than 15% by weight of cement is used. This behaviour suggests that CPA possesses pozzolanic characteristics.

3.4 Strength Activity Index (SAI)

The strength activity index (SAI) is a measure of the pozzolanicity of supplementary cementitious material (SCM) and is measured as the strength relative to the control, in percent. For a SCM to be classified as pozzolan, the strength of the blended cement at 7-day and/or 28-day must not be less than 75% of strength of normal concrete (ASTM C 618-08). The SAIs of the cement-CPA blended concrete are also presented in Table 3. It is shown that, at 7-day, only concrete with 5% CPA met the minimum permissible limit (75%) but thereafter, i.e. at 28-day and beyond, the minimum SAIs for 5%, 10% and 15% is 79% ,which is greater than the minimum recommended; suggesting pozzolanic activity occurring during this period. This signifies that up to 15% CPA could be adjudged as optimum replacement levels of cement with CPA for blended concrete production. As the development of calcium-silicate-hydrate (C-S-H) gel is a phase responsible for strength gaining, it is likely that with optimum substitution of cement with CPA, formation of this phase is initially inhibited and then allowed to develop at a later age, resulting in strength increase with age. Conversely, for 20 and 25% CPA, the SAIs for all the ages were below 75%. It is observed that there was no appreciable increase in the SAIs for this replacement with increase in age. Thus, CPA above 15% is not recommended for use where strength is a criterion.

3.5 Strength Models for Cement-CPA Blended Concrete

A 2nd degree polynomial regression, using curves in Figure 3, involving the compressive strength (f_c) and curing ages (C_a) for the optimum CPA content (0-15%) proposes the equations for predicting the compressive strength of cement-CPA blended concrete. These equations and correlation coefficients (R) are as follows:

For 0% CPA

$$f_c = 0.00043C_a^2 + 0.104C_a + 15.93 \qquad (R = 0.999) \qquad (1)$$

For 5% CPA

$$f_c = 0.00069C_a^2 + 0.176C_a + 10.89 \qquad (R = 0.999) \qquad (2)$$

For 10% CPA

$$f_c = 0.00068C_a^2 + 0.169C_a + 10.50 \qquad (R = 0.999) \qquad (3)$$

For 15% CPA

$$f_c = 0.00086C_a^2 + 0.182C_a + 9.71 \qquad (R = 0.999) \qquad (4)$$

Since the correlation coefficients are close to 1, it shows that the formulas can best describe the relationship, statistically, between compressive strength and curing ages for different levels of CPA replacement. The equations show that the coefficient of the curing age for 5 to 15% CPA are each greater than that of the control. This further suggests that CPA, like any other pozzolanic materials, contributes to later strength of concrete.

Experimental data and the predicted values on the bases of these equations were compared by subjecting them to analysis of variance (ANOVA). The results show that there is no statistical significant difference between the two values ($\rho > 0$) at 95% confidence level. This suggests that the formulae can be used to predict the compressive strength at any given age of CPA concrete.

3.6 Flexural Strength of CCPA Blended Concrete Beam

Flexural strength of a concrete is its ability to resist failure due to bending. It is expressed as the *modulus of rupture* (MR) in N/mm^2. At the point of loading the concrete beam specimen, the top half of the beam is subjected to compression and the bottom half is subjected to tension with the critical (failure) section at the middle third of the span, where maximum flexural moment occurs. During initial loading, no noticeable crack was observed. It was suspected that the maximum tensile stress in the concrete was less than the modulus of rupture. Thus, the entire section of the concrete beam acts to resist the bending moment. When the maximum tensile stress in the un-cracked beam reaches the modulus of rupture, the concrete cracks which extends from the tension face to the neutral surface then moves further toward the compressive face and the concrete beam failed. It was observed that the crack occurs within the middle third portion of the beam for all the mixes and that the failure mode was independent of the amount of CPA in the concrete beam. Concrete being a brittle material, the failure was rapid since it was not reinforced.

As crack occurred within the middle third of the beam span, MR was computed on the basis of Equation (1) of ASTM C78. Figure 4 shows the variation of flexural strength with cassava peel ash replacement percentage at different curing ages. Similar pattern is observed for flexural strength as for compressive strength. The flexural strength increases with curing age for all the mixes. However, it decreases with increase in CPA content compared to the normal concrete (control with 0% CPA). Figure 4 further shows that flexural strengths of concrete with 5, 10 and 15% CPA tend to meet up with that of normal concrete at later ages of 90 and 120 days. On computing percentage differences with respect to control at 120 days, the values of the average difference at 5%, 10%, and 15% replacement levels are obtained as 4.1%, 6.8% and 11.4% respectively. In reinforced concrete members, little dependence is placed on the flexural strength of concrete since steel reinforcing bars are incorporated to resist tensile stress.

3.7 Relationship between Compressive and Flexural Strength of CCPA Blended Concrete

Once a satisfactory relationship between flexural and compressive strength is established, flexural strength can be predicted on the basis of compressive strength of concrete especially in pavement design (Shetty, 2006).

The flexural strengths and strength ratios, SR, (ratio of flexural to compressive strength) for all the mixes at different curing ages were computed and presented in Table 4. It is observed that SR for normal concrete was between 0.09 and 0.10 for all the ages, showing that flexural strength is just about 9-10% of the compressive strength. This value falls within the range of 0.08 to 0.11 (Shetty, 2006). But for all other mixes with different replacement levels of CPA, the SR ranges between 0.09 and 0.12.

4. Conclusions and Recommendations

Flexural and compressive strength characteristics of cement-cassava peel ash blended concrete were studied and the effect of replacement levels of cement with CPA on workability of CPA concrete was equally assessed using slump and compacting factor tests. The study concludes as follows:

1. As CPA content increases, water-binder ratio (w/b) to achieve workable blended concrete also increases. It is suggested that an optimum w/b of 0.7 may be appropriate.
2. Compressive and flexural strengths increase with age but reduce with increase in CPA content in the mix especially when more than 15% CPA is used.
3. CPA appears to contribute to late strength development of concrete when up to 15% by weight of cement is

used as indicated by the Strength Activity Index (SAI) which is above minimum recommended of 75% at 28 days and above.

4. Models showing quadratic relationship between compressive strength and curing age for up to 15% CPA using regression analysis are suggested.
5. A maximum of 15% CPA with water binder ratio of 0.70 is recommended to produce cement-CPA blended concrete of appropriate strength.

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- *M. A. Salau (Ph.D) is a Professor of Engineering at the Civil & Environmental Engineering Department, Faculty of Engineering, University of Lagos, Nigeria. Salau is a member of the Nigerian Society of Engineers and a COREN registered and practicing engineer in Nigeria. He has published over sixty (60) articles in local and international journals and conferences. He has successfully produced over ten (10) M.Phil. and Ph.D candidates. His areas of research interest include natural fibres as reinforcement in concrete and pozzolans. Tel.: +2348033303420, E-mail.: ajibsalau@yahoo.co.uk*
- *E. E. Ikponmwosa is an Associate Professor at the Civil & Environmental Engineering Department, Faculty of Engineering, University of Lagos, Nigeria. Ikponmwosa is a member of the Nigerian Society of Engineers and a COREN registered and practicing engineer in Nigeria. He has published over twenty (20) articles in local and international journals and conferences. He has successfully produced many students at the graduate and M.Phil. levels. He is currently working jointly with others to produce Ph.D candidates. His area of research focus is materials and structures and pozzolans. Tel.: +2348055897732, E-mail.: efe_ewaen@yahoo.com or eikponmwosa@unilag.edu.ng*
- *K. A. Olonode is currently pursuing Doctor of Philosophy degree program in Materials & Structures at the Civil & Environmental Engineering Department of the University of Lagos, Nigeria. He is a member of the Nigerian Society of Engineers and a COREN registered and practicing engineer in Nigeria. He is a lecturer at the Obafemi Awolowo University, Ile-Ife, Nigeria. Tel. +2347036439726, E-mail:makkolawole@yahoo.com*

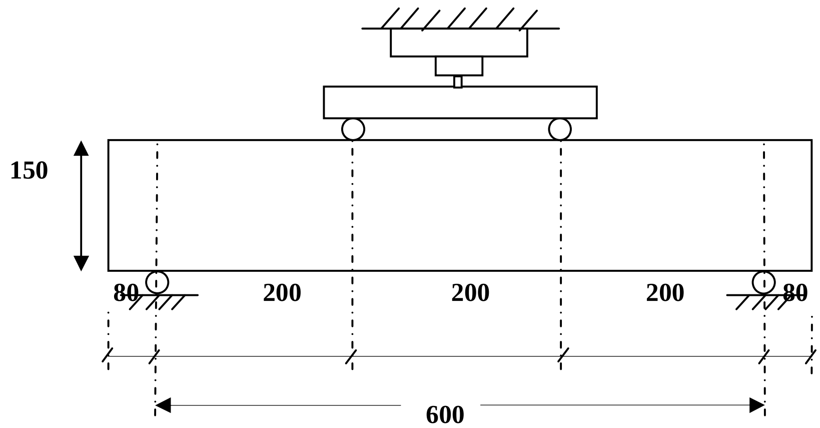

Figure 1: Experimental set-up for flexural strength test.

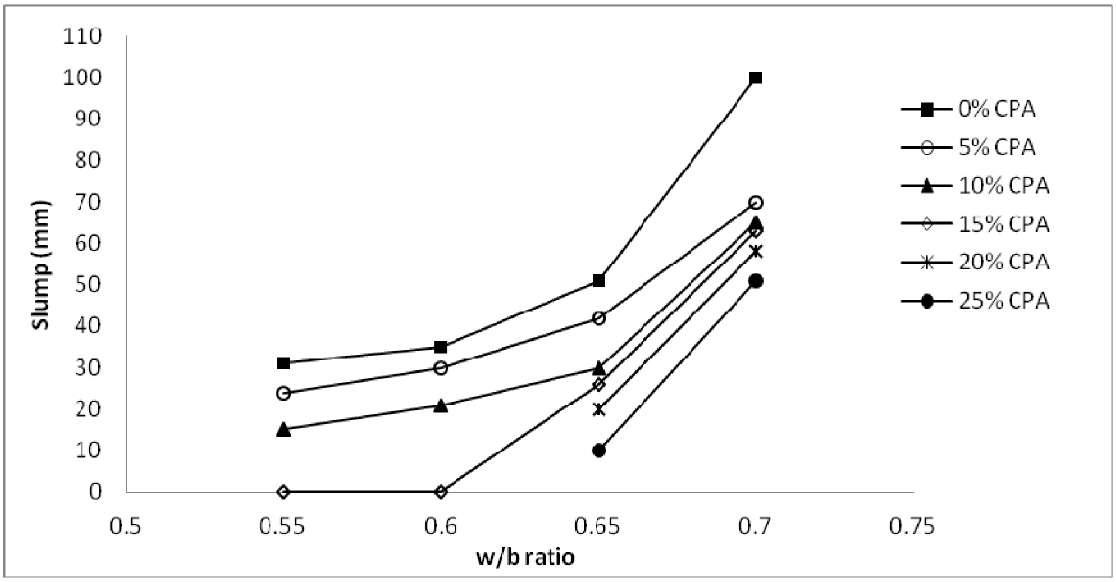

Figure 2: Effect of w/b ratio on slump of cement-CPA blended concrete

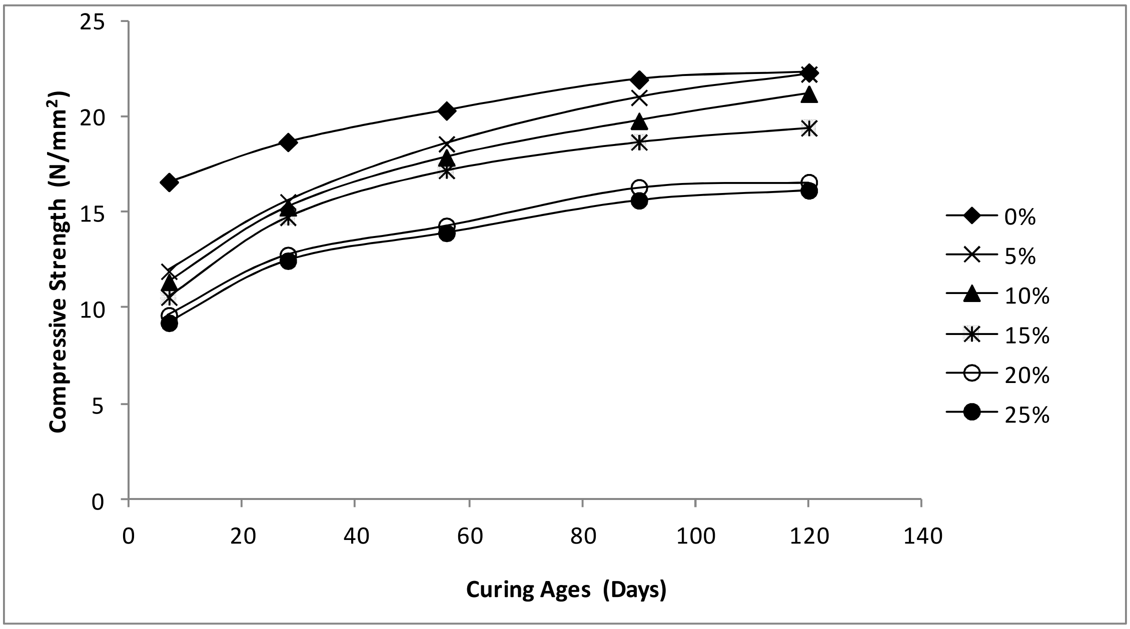

Figure 3: Compressive strength of concrete at various curing ages for different contents of CPA.

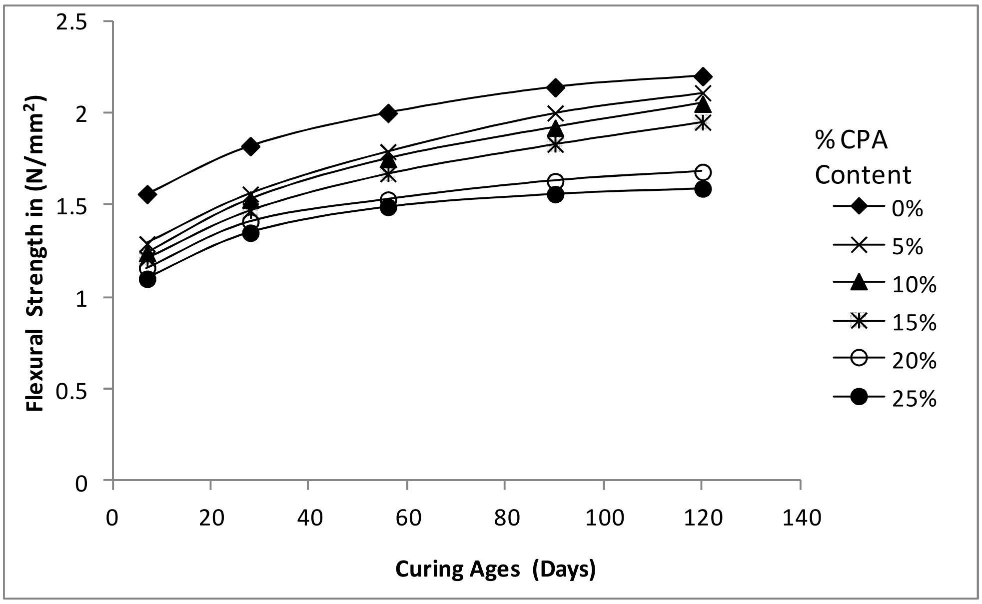

Figure 4: Flexural strength of concrete at various curing ages for different contents of CPA.

Table 1: Properties of CPA and Cement

Material	Chemical composition (%)									Physical properties	
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	LOI	Sp. gravity	Fineness (m^2/Kg)
CPA[a]	58.02	12.80	1.41	8.53	5.02	2.18	7.67	0.03	4.18	0.32[b]	330
OPC	18.33	5.00	2.75	60.11	1.15	3.21	0.08	0.00	7.22	3.09	355

a: Salau and Olonade (2011)

b: It was not included in the Source but was freshly determined.

Table 2: Effect of water-binder ratio (w/b) on slump and compacting factor of the Blended Concrete

%CPA	Slump (mm)				Compacting Factor			
	Water-binder ratio (w/b)				Water-binder ratio (w/b)			
	0.55	**0.60**	**0.65**	**0.70**	**0.55**	**0.60**	**0.65**	**0.70**
0	31	35	51	100	0.895	0.884	0.907	0.915
5	24	30	42	70	0.894	0.893	0.909	0.915
10	15	21	30	65	0.891	0.898	0.907	0.915
15	0	0	26	63	*	0.897	0.905	0.916
20	*	*	20	58	*	*	0.901	0.923
25	*	*	10	51	*	*	0.894	0.925

* Mix was not possible.

Table 3: Density, Compressive Strength (CS) (N/mm^2) and Strength Activity Index (SAI)

% CPA	Density (Kg/m^3) Curing Ages (Days)					Curing Ages (Days)									
						7		**28**		**56**		**90**		**120**	
	7	**28**	**56**	**90**	**120**	**CS**	**SAI**	**CS**	**SAI**	**CS**	**SAI**	**CS**	**SAI**	**CS**	**SAI**
0	2414	2414	2427	2483	2469	16.6	100	18.7	**100**	20.3	**100**	21.9	**100**	22.3	**100**
5	2456	2405	2423	2421	2468	11.9	72	15.6	**83**	18.6	**91**	21.0	**96**	22.2	**99**
10	2427	2452	2473	2417	2427	11.4	68	15.3	**82**	17.9	**88**	19.8	**90**	21.2	**95**
15	2420	2456	2441	2441	2436	10.6	64	14.7	**79**	17.2	**85**	18.7	**85**	19.4	**87**
20	2425	2437	2431	2439	2431	9.6	58	12.8	**68**	14.3	**70**	16.3	**74**	16.6	**74**
25	2438	2428	2421	2466	2425	9.2	56	12.5	**67**	13.9	**69**	15.6	**71**	16.2	**72**

Table 4: Flexural Strength (FS) and Corresponding Strength Ratio (SR)

CPA (%)	**Curing Age (Days)**									
	7		**28**		**56**		**90**		**120**	
	FS	**SR**	**FS**	**SR**	**FS**	**SR**	**FS**	**SR**	**FS**	**SR**
0	1.56	0.09	1.82	0.10	2.00	0.10	2.14	0.10	2.2	0.10
5	1.29	0.11	1.56	0.10	1.79	0.10	2.00	0.10	2.11	0.09
10	1.24	0.11	1.53	0.10	1.7	0.10	1.87	0.09	1.97	0.09
15	1.21	0.11	1.47	0.10	1.62	0.09	1.77	0.09	1.8	0.09
20	1.16	0.12	1.41	0.11	1.53	0.11	1.63	0.10	1.68	0.10
25	1.1	0.12	1.35	0.11	1.49	0.11	1.56	0.10	1.59	0.10