CHARACTERISATION OF CORNCOB ASH POZZOLAN ANDITS PERFORMANCE IN CONCRETE

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Abstract

Concrete has been known to exhibits outstanding qualities in the construction of modern infrastructure, andcement as a major constituent, performs a vital role in the production of concrete. Due to increasing demand, cost of cement and the emission of CO_2 generated during the pyro process have led to the utilization of supplementary cementitious materials such as Corncob Ash (CCA) to partially replace cement in concrete. This research work examined the pozzolanic, physical and mechanical properties of CCA- blended cement and concrete. The CCA content was varied at 0, 10, 20 and 30% in partial replacement of cement. The concrete mix ratio of 1:2:4 and water/cement of 0.6 were used to cast 150 mm concrete cubes, cured and tested at 28, 60, 90 and 120 days for strength. The CCA contained 74.3% of SiO_2, Al_2O_3 and Fe_3O_2, which characterized it as a pozzolan, with 6.93% loss on ignition (LOI).Compressive strength test performance at 28 days were 20.56 N/mm^2 for 10%, 17.05 N/mm^2 for 20% and 13.54 N/mm^2 for 30% ashes content respectively, while the control was 22.52 N/mm^2. The strength decreased as the ash percentage increased. The work revealed that the corncob ash is a good Supplementary CementitiousMaterial (SCM) and the performance in structural strength of the concrete could be tolerated up to 10% ash for load bearing structures.

Keywords: Pozzolan, cementitious, loss on ignition, compressive strength.

Introduction

One of the most important issues in the world today involves the built environment. It is well accepted by everyone that concrete executes outstanding responsibilities for construction of modern infrastructure. Concrete is a construction materials which comprises of the mixture of three constituents materials namely, cement, water and aggregates. Each of these materials determines the strength that any concrete would possess (Gambhir, 2004). Therefore, the overall cost of the concrete production depends largely on the availability and cost of its constituent materials. Among these three basic constituents cement is the most expensive and contributes to environmental pollution.

In Nigeria, some 20 million tonnes of cement worth 350 billion naira are consumed annually, with an associated CO_2 emission of 20 million metrictonnes (Adeloye, 2011). Olutoge*et al.* (2010) observed that about 7% of the world's CO_2 emission is attributed to Portland cement industry. CO_2 emissions from the manufacturing of cement showed that 46.3% of the CO_2 released is from the chemical reaction of the pyro process. The 46.3% CO_2 emission during pyro processing is inherent in the nature of the raw materials undergoing chemical reactions; improvement in furnace technology will have little effect on this category (United State Department of Energy, 2003). Portland cement the commonly used type around the world today has been experiencing a steady rise in cost due to high demand for the materials (Bentur, 2002, Massazza, 1974 & 1993).

In order to reduce high cost and environmental pollution due to cement production and usage, certain low cost materials that have supplementary cementitious materials (SCM) or pozzolanic properties to partially replace Portland cement in concrete mixtures is required. The low cost material often used are industrial or agricultural by-products waste, such as fly ash (FA) , blast furnace slag (BFA), rice husk ash (RHA), corncob ash (CCA), etc., that requires less energy to manufacture (Bapat, 2011). Neil and Ravinda (1996) highlighted that the numerous benefits or properties commonly modified with these materials are the heat of hydration, accelerate or retard setting time, workability, water reduction dispersion and air entrainment, impermeability and durability.

Strength Development of Mortar and Concrete with Pozzolans

Adesanya and Raheem (2009) studied the use of CCA blended cement produced in a controlled environment of a factory to produce concrete specimens. The study showed that the compressive strength for the CCA – blended cement is lower than that of the plain cement (the control) at early curing ages but improves significantly at later ages. The study now concluded that there is need to look for ways of increasing the strength at early ages. Raheem *et al*. (2010) investigated the effect of admixtures on the properties of corncob ash (CCA) cement concrete. The workability and compressive strength of CCA cement concrete incorporated plasticizers, water reducing and retarding were carried without accelerator. The result showed that CCA cement incorporated accelerator achieved greater strength at early ages, plasticizer achieved very high strength at both early and old ages while with water reducing and retarding achieved greater strength at old ages alone.

Kevern and Wang (2010) investigated high silica corn ash (HSCA) and regular corn ash (RCA), there are similarity in chemical composition as they contained high levels of SiO_2 (35.6% and 38.3%), K_2O (24% and 27.6% respectively). The mortar with up to 10% HSCA replacement for Portland cement produced comparative compressive strength values to mortar made with 100% Portland cement and significantly higher compressive strength values than sample using the regular corn ash (RCA). They concluded that increase in compressive strength between the HSCA and the RCA can be attributed to smaller particle size of the HSCA. The chemical analysis also indicated a higher level of magnesium (Mg) in the HSCA which could also contribute to higher compressive strength. They therefore opined that corn ash may have the potential for application in third-world countries to extend their supply.

Strength development of fly ash (FA) mixed mortar was investigated. OPC was partially replaced by 20 and 40% with ground palm oil fuel ash, ground rice husk and classified fuel fly-ash in a research (Chindaprasit & Rukzan 2008). They found that compressive strength of cement pastes similar to 20% replacement of pozzolan but in the case of 40% dosage, a significant strength decreasing trend were observed with an increment in the replacement of pozzolans at the age of 7 days. But, at the age of 28days, the strength of pastes containing pozzolans, were approximately the same as that of OPC paste. Different results were found at 90 days, the strength of paste containing pozzolans were slightly higher than that of OPC placed by up to 6 MPa. This greater strength development character at later age exhibits the characteristics of pozzolanic materials.

Therefore FA replacement in mortar and concrete would be remarkable cement saving as well as cost minimizing steps for the construction of concrete structures without sacrificing the strength of concrete. It is summarized that FA could perform an imperative role as a supplementary alternative of cementing material in concrete construction (Karim *et al.*, 2011).

Class F fine fly ash with a finesse of 99% passing a 45 µm sieve was used in a research by Haque and Kayali (1998) to produce workable high strength concrete. Test result represent 20% increase in strength as compared to the corresponding concrete without fine FA, the water penetrability was about 28% less than the corresponding plain concretes they concluded that by proper utilization of the fine FA, it would produce both high strength and high performance concrete.

Research Materials and Methodology

These research work focus on the use of agricultural waste or product of maize called corncob, Plate 1. Corncob ash is an agricultural by product or waste generated by combustion under an elevated temperature. The research determined the supplementary cementitious materials in the cob and uses the ash at 0, 10, 20 and 30% to partially replace cement to determine the physical and mechanical properties of concrete.

Materials and Specimen Preparation

The cobwas pre-burnt in an incinerator to reduce the volume of shaft and subjected to further heating in an electrical furnace, calcined to 1000^{o}C, kept at this temperature for 2 hours. Rapid cooling was achieved with the furnace switched off and allowed to cool at room temperature. Ash burnt at this temperature is highly reactive and rich in amorphous silica. After cooling, the ash was further grounded in a grinding machine, sieved, passed through 150 µm and retained on 100 µm sieve size. This was taken to the laboratory for chemical analysis.

Plate 1: Corncob dumpsite

Chemical Analysis of the Ash

2 grams sample of the fine ash was weighed, 20 ml nitric acid and chloric acid in the ratio 2:1 was added in crucibles to reduce the melting, digested in muffle furnace at 150^oC for 30 mins. Additional HCL was added, temperature increased to 230^oC digested for 1 hour 30 mins and allowed to cool at room temperature. 20 ml of distilled water was added to the digested sample and washed into 50 mls standard volumetric flask. Compound like Ca, Mg, Si, Al, and Fe oxides were determined on an Atomic Absorption Spectrum photometer (model Burk 210 VGP) Plate 2, which uses a light beam to excite these ground state atoms absorbed in the flame and relate it to concentration of a standard sample whichwere measured colorimetrically, while Na and K were determined on a flame photo spectrometer (model corning 410) Plate 3, as the sample was raised to a high temperature causing emission of light. Each element had a characteristic set of wavelength and the intensity of emission was used to calculate the concentration according to their presence on periodic table.

Cement

Portland cement is hydraulic cement composed primarily of hydraulic calcium silicates. Hydraulic cements set and harden by reacting chemically with water during the reaction called hydration. Cement is made from limestone and generally produced by dry or wet process. Cement compounds are basically made of tricalcium silicate (C_3S), dicalcium silicate (C_2S) and tricalcium aluminate (C_3A), where C, S, A represent CaO, SiO_2 and Al_2O (Omotosoa *et al.,* 1995) with C_3S and C_2S being the main cementitious compounds.

Consistency and Setting Times of Cement and Ash

Consistency of cement is used to determine the amount of water content to make a standard paste and is usually between the range of 26-33%penetrationof plunger 5-7mm depth from the bottom of mixed paste in a mould placed on Vicat's apparatus while the setting times determines the initial and final setting times of the set blended ash cement (Neville & Brooks 2008). It is also measured at 34mm depth by 1.13±0.05mm needle penetration inside a mould placed on vicat's apparatus.

Plate 2: Atomic absorption spectrometer test equipment

Plate 3: Flame photo spectrometer test equipment

Soundness and specific gravity of ash and cement

Soundness determines the amount of free limes and magnesium in the cement and ash that makes the set paste to expand. This is measured by using Le-chatilier's apparatus, and water bath to raise the temperature of the set paste to 100^{o}C boiling point and see if there is expansion on the set paste (Neville & Brooks, 2008).

Specific gravity (S.G) shows the quality of materials as it compares the ratio of the weight of giving volumes of substance i.e. cement and the corncob ash to the weight of equal volume of water.This is determine by using pycnometer or density bottle filled with a known weight of cement to reach a mark point on the bottle, then filled with volume of ash to reach the marked point and weighed, add distilled water to the cement and ash separately inside the bottle to reach the brim and weighed respectively. Empty the bottle wiped it thoroughly and weighed. Using equation 1, determine the specific gravity of the cement, ash and combined separately.

$$S.G = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \text{.................................} (1)$$

Concrete constituents

Aggregates: Fine aggregates (sand) used for the research was obtained from Ogun riverand the coarse aggregates (granite) used was crushed rock obtained from a quarry in Abeokuta, Ogun state. According to BS 812 (1985), gradation is the particle size distribution of an aggregate as determined by sieve analysis. The range of particle sizes used for the fine aggregate was between 0.15- 4.75 and fineness modulus (FM) of 2.7 which made the aggregate to be medium sand while the coarse aggregates range from 10 – 32 mm in size, this enable the fines to fill the void created by the coarse aggregate. In general the aggregates did not have a large deficiency or excess of any size, this relatively assisted aggregate proportion as well as cement and water requirement but with improved workability, pumpability, economy, porosity, shrinkage and durability of concrete (Neville & Brooks, 2008).

Water: The water samples used for mixing the concrete were clean and free from oil; the fresh water used was a tap water obtained from thedepartment of civil engineering laboratory, MoshoodAbiola Polytechnic, Abeokuta.

Method of Atching Concrete

Batching was done by weighing the materials for the control and specimens i.e. cement, corncob ash, water, fine and coarse aggregates using an automatic weighing balance. Concrete mix ratio of 1:2:4 by weight of concrete and 0.6 water cement ratio were used. Part was set as control while others are specimen with CCA addition at 10, 20 and 30% Table 1.

Table 1: Mix proportion for 48 concrete cubes

Admixture Type	Cement (kg)	Corn cob ash (kg)	Sand (kg)	Coarse aggregate (kg)	Water (kg)
100% OPC	18.05	0	36.10	72.2	10.83
10% CCA	16.25	1.80	36.10	72.2	10.83
20% CCA	14.43	3.62	36.10	72.2	10.83
30% CCA	12.62	5.43	36.10	72.2	10.83

Method of Mixing

The mixing was done manually on a clean concrete floor and the materials were thoroughly mixed in the dry state, after which water was added gradually while mixing the concrete until the water weighed (Table 1) had been used, making it uniform in color and consistency.

Test for Workability

Slump Test: The slump is a measure indicating the consistency or workability of cement concrete. The test was carried out according to BS 1881-102: 1983. It gives an idea of water content needed for concrete to be used. The mould used for slump test was a frustum of cone, 300 mm high, with base of 200 mm diameter and smaller opening of 100 mm diameter at the top. The mould and its base were moistened using lubricating oil, in order to reduce the influence on the variation in the surface friction. The mould was held firmly against its base and the mould was filled with concrete in three layers, each layer wasrodded 25 times with a standard 16 mm diameter steel rod. Immediately after filling, the cone was slowly lifted, the unsupported concrete slumped was measured by subtracting the height of the concrete slumped from the slump cone mould used. The pattern of slump indicates the characteristics of concrete to beeithertrue, sheared or collapsed slump.

Compacting Factor Test: The apparatus consist essentially of two hoppers each in the shape of a frustum of a cone with doors and one cylinder at the bottom BS 1881-103:1983.

The upper hopper is filled with concrete placed gently, to avoid work done on the concreteafter filling with concrete, the bottom door of the hopper was then released and the concrete falls into the lower hopper. This hopper is smaller than the upper one and therefore filled to overflowing.

The bottom door of the lower hopper was also released and the concrete falls into the cylinder, excess concrete on the cylinder was cut by straight edge across the top of mould, the net mass of concrete in the cylinder was weighed. The ratio of weight of concrete in the cylinder to the weight of the fully compacted concrete is defined as the compacting factor. The weight of the fully compacted one was obtained by first weighing empty cylinder and subtract from the compacted one which gave the weight of the fully compacted concrete.

Placing and Compaction of Concrete: Wooden mould of size 150 mm x 150 mm x 150 mm was used to cast 48 concrete cube specimens. The inside of the wooden mould was primed with oil so as to enhance easy removal of the set concrete. The fresh concrete mix for each batch was fully compacted by tamping rod, to remove trapped air, which can reduce the strength of the concrete. But before the concrete was placed and cast, it was tested for slump and compacting factor. The concrete cubes were then demoulded after 24 hrs. Specimens were stacked and cured in water at different ages and tested for compressive strength in the laboratory.

Compressive strength test of concrete cubes: The concrete cubes were cured for 28, 60, 90 and 120 days taken out 24 hrs prior to crushing, weighed, calculate the densities of the hardened concrete cubes and tested for strength on ELE compact-150 type compression test machine Plate 5 and the compressive strength determined using the ratio of Force/Area.

Analysis of Variance (ANOVA)

A two – way ANOVA was used to determine whether there are significant variations in compressive strength and densities of concrete specimens among different ratios by weight of ash blended concrete with different days of curing and hypotheses were tested.

Plate 4: Weighing concrete cube

Plate 5: Crushing concrete cube on compression machine

Result and Discussion

Chemical composition of corncob ash and cement (%)

Each element has a characteristic set of wavelength and the intensity of emission was used to determine the concentration according to their presence on periodic table. Considering the chemical composition of the ash Table 2,the combination of the silicates, aluminates and ferric oxides i.e. SiO_2, Al_2O_3 and Fe_2O_3 resulted in 74.3% with LOI of 6.93% and low content of CaOof 1.68%,these properties classified the ash to be a pozzolan or supplementary cementitious materials (SCM). According to ASTMC 618, when the sum percent of SiO_2, Al_2O_3 and Fe_2O_3 exceed 70%, and loss on ignition (LOI) less than10%, the ash belongs to class F and generally seen as class F ash, containing low content of CaO, the ash exhibit pozzolanic properties. Therefore the corncob ash CCA can be used as supplementary cementitious materials in cement mortar and concrete production. Comparing the ash and cement, it shows that the elements are the same except CaO of 65.4% which are predominant in cement with SiO_2 20.9%, Al_2O_3 4.8%and Fe_2O_3 3.4%.

Table 2: Chemical composition of corncob ash and cement (%)

Chemical comp. of Ash (%)	Sample1	Sample2	Sample3	Average % comp.	Chemicalcomp. of cement (%) (control)
CaO	1.69	1,67	1.68	1.68	65.4
MgO	0.87	0.86	0.90	0.89	1.3
Na_2O	0.61	0.64	0.59	0.67	0.2
K_2O	2.13	2.20	2.10	2.14	0.4
Fe_2O_3	3.21	3.29	3.19	3.23	3.4
SO_3	0.58	0.59	0.55	0.57	2.7
Al_2O_3	7.25	7.18	7.15	7.19	4.8
SiO_2	63.85	64.25	63.55	63.88	20.9
$SiO_2 + Al_2O_3 + Fe_2O_3$				74.3	
LOI	6.94	6.95	6.90	6.93	0.9

Normal consistency and setting times of cement and corncob ash

These properties are so essential for proper mixing and construction of concrete for any types of structure. Test showed that the normal consistency of ordinary portland cement (OPC) paste was 30.8% while those of original disposed CCA cement pastes were between 34.4 and 35.6% Table 3. It was depicted from this table that the normal consistency of disposed CCA cement paste increases with increasing percent of CCA in the mix. This can be attributedto the high porosity of the particles and also due to finely grounded CCA which absorbed water and resulted in higher water consumption (Cheerarot & Jaturapitalkkul 2004). Therefore the water content to make a standard paste of cement was 30.8% and for the blended ash cement at 10, 20 and 30% additions ranges between 34 and 35.6%.

Setting time refers to a change from liquid to rigid state (Neville & Brooks, 2008). The use of CCA in checking the setting time of cement was also investigated. The result showed that the initial and final setting times of cement (control) was between 2 hours 15 minutes and 3 hours 45 minutes, at ratio of 10: 90 the initial and final setting times was reduced to between 40 minutes and 2 hours 15 minutes, at ratio 20:80 it increased to between 2 hours 49 minutes and 5 hours 51 minutes and at 30:70, there was a reduction in the initial setting to 1 hour 45 minutes but the final setting was achieved at 10 hours later Table 3.

Table3: Normal consistency and setting times of CCA: OPC mixed cement paste

CCA:OPC by weight	Normal Consistency %	Initial Setting Time (hr:min)	Final Setting Time (hr:min)
00:100	30.8	2:15	3:45
10:90	34.4	0:40	2:15
20:40	35.6	2:49	5:51
30:70	35.3	1:45	10+

Soundness and Specific Gravity of CCA: OPC Mixed Paste

Soundness referred to the ability of hardened cement paste to retain its volume after setting without expansion, Result conducted on the cement and ash cement paste indicated that there was low expansion on the ash cement paste, the expansionranged between 1.23 -2.40 mm of the disposed CCAat 10 and 20% respectively with the control expansion of 2.30 mm which was less than 10 mm limit, but at ratio 30:70 where the final setting was after 10 hours, the partially hardened ash cement paste could not sustain the temperature and finally dissolved at 100^{o}C.This shows that there was enough amount of free CaO and MgO (Neville and Brooks 2008) present in the mix at 30% ash because the oxide slowly hydrate and could not set thereby expanded and dissolved totally Table 4.

Specific gravity (S.G) shows the quality of materials as it defines the ratio of the volume materials to the equal volume of water. The specific gravity of cement ranges from 3.0-3.25 ASTM C128-12. For the ordinary portland cement used, the value obtained was 3.12 which were still within the acceptable range. The ordinary CCA's specific gravity was 1.87. In comparison, the specific gravity of cement shows that the materials composition of cement is heavier in term of weight and quality than the organic biomass of CCA which is lighter. The S.G of partially replaced cement with CCA at 10% increased the value to 2.69 and decrease to 2.64 and 2.54 as the percent addition of CCA increases from 20 to 30%. It shows that the OPC perform better in term of specific gravity Table 4.

Table 4: Specific gravity and soundness of CCA: OPC mixed paste

CCA:OPC %	Specific gravity	Soundness (mm)
0:100	3.12	2.30
100:0	1.87	-
10:90	2.69	1.23
20:80	2.64	2.40
30:70	2.54	0

Test for workability

Slump and Compacting Factor Test: Slump test shows the consistency of the mixture not to be too wet, dry or stiff. The slump of the mixes was true slump of which the control was high and reduced as the ash percent increases. Table 5showed the result of the slump values. The result showed that the control slump of 99 mm decreased to 90 mm at 10%, 74 mm at 20% and 69 mm at 30% addition of the ash confirming the tested samples to reduce in workability and riches in mixture of the blended concrete.

Compacting factor determined the workability of the concrete. It must be less than 1(one) for the concrete to be workable (Neville and Brooks 2008). The control test was measured to be 0.98 and same for 10% CCA content and decreases to 0.96 and 0.94 respectively for 20 and 30% ash concentration Table 5. It showed therefore that the concrete becomes less workable as the ash content increases.

Table 5: Slump test and Compacting factor test value

CCA:OPC %	Slump (mm)	Compacting factor (mm)
00:100	99	0.98
10:90	90	0.98
20:80	74	0.96
30:70	69	0.94

Test for Density of Hardened Concrete: Density development of CCA blended hardened concrete were carried out. The densities increased along with ages of curing. At 0% ash (control) the densities increasedfrom 28 - 120 days to between 2475 - 2581 kg/m^3, for 10% ash concentration the densities increasedfrom 28 - 120 days to between 2358 – 2464 kg/m^3, the trend continues for 20 and 30% ash concentration. Figure 1 showed that as the age's increases, the concrete continued to be denser, likewise the tested samples of 10, 20, and 30% but the main concern was the reduction in densities as the ash content increases. It showed that the CCA can be used for lightweight concrete structure.

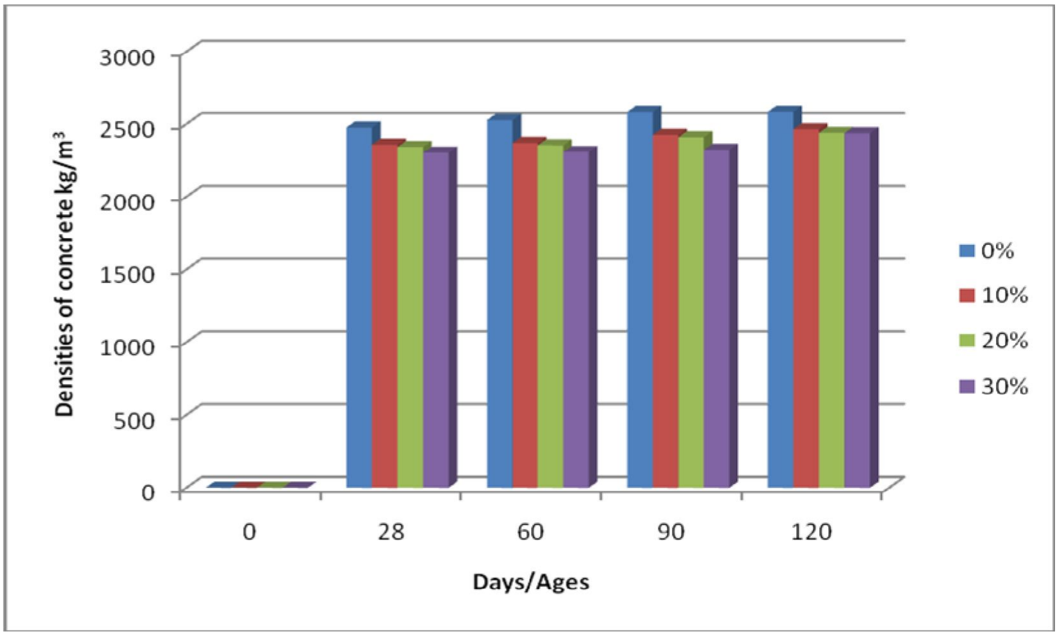

Figure 1: Densities of CCA mixed concrete

Compressive Strength of Concrete: The characteristic compressive strength of concrete cubesincreases as the curing age increased and decreased as ash content increases, as shown in Figure 2. At 10% ash, compressive strength at 28 days was 20.56 N/mm^2 which was less than the control value of 22.52 N/mm^{2}which falls just below the designed strength of 25 N/mm^2 but adequate for a designed strength of 20 N/mm^2 . As the curing ages increase the strength improves in value to 23.92 N/mm^2 this was in agreement with Adesanya and Raheem (2009). At 120 days, the compressive strength was 20.67 N/mm^2 which shows slow development of strength,Toutanji *et al*, (2004) opined that in order to fully benefit from the addition of these supplementary cementitious materials to concrete, a long period of curing is necessary and if early strength of concrete is required, the use of plasticizers is advantageous.Thereforethere is an indication that the 20% ash meets the characteristic design strength of concrete and can be used for light-weight concrete structure.

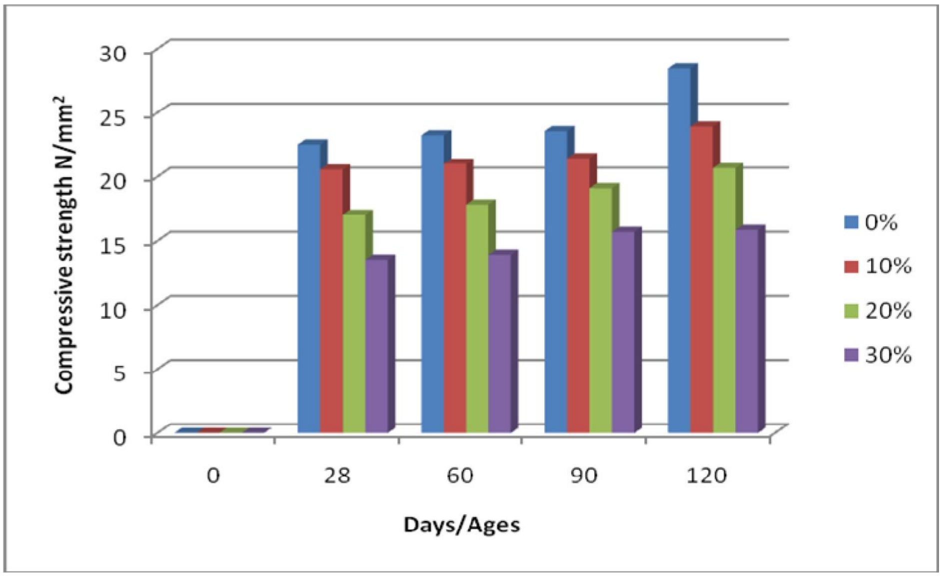

Figure 2: Compressive strength of CCA mixed concrete

ANOVA Test Result on Densities and Compressive Strengths: The result in Tables 6 and 7 showed that there are significant difference in densities and compressive strength of concrete at different mix proportion (cement and ash) ($p<0.05$). Also, there are significant differences in densities and compressive strength of the concrete at different curing ages ($p<0.05$).

Table 6: ANOVA test of densities (kg/m^3)

Source of variation	SS	df	MS	F	P-value	F crit
CCA:OPC by weight	88225.5	3	29408.5	62.204	2.439E-06	3.863
Densities (kg/m^3) of CCA mixed concrete at days	29278.5	3	9759.5	20.643	2.261E-05	3.863
Error	4255	9	472.778			
Total	121759	15				

Table 7: ANOVA test of compressive strengths (N/mm^2)

Source of variation	SS	df	MS	F	P-value	F crit
CCA:OPC by weight	207.954	3	69.318	90.877	4.759E-07	3.863
Compressive strength at days	33.518	3	11.173	14.648	8.263E-05	3.863
Error	6.865	9	0.763			
Total	248.337	15				

Conclusions

Corn cob ash possessed the properties of supplementary cementitious material; it contained 74.3% of Al_2O_3, SiO_3 and Fe_2O_3 that made it to be pozzolan. The consistency of cement at 30.8% water content made the initial and final setting times of disposed ash cement reducedhydration timefrom 2 hours 15 minutes and 3 hours 45 minutes of control to 40 minutes and 2 hours 15 minutes at 10% ash. Soundness another property that determines free CaO and MgO which might cause expansion in the blended cement and made it unsound, were within acceptablelimit of1.23 – 2.4 < 10 mm at 10 and 20%, it was only at 30% that the paste was unsound because the blended cement dissolved at $100^{O}C$ due to prolong final setting time of ash blended cement. The specific gravity of the ordinary corncob ash of 1.87 was even lower than the specific gravity of cement of 3.12; it showed that the quality ofcement was better than that of ash.

Densities of CCA blended concrete showed that the concrete decreased in densitiesbut increased between the curing period from 2358 to 2464 kg/m^3 as against the control of 2475 to 2581 kg/m^3between 28 and 120 days curing time respectively indication of low density performance of ash blended concrete but still meet the required density of concrete.Strength development in terms of compressive strength of the concretecube has revealed that there is lower value of compressive strength of 20.56 N/mm^2 at 10% ash as compared to 22.52 N/mm^2 of control at 28 days strength which met characteristic design strength of 20 $N/mm^2$of concrete. However, an important pozzolan characteristic is the slow development of strength which implies that 20% corn cob ash developed the required strength over a period of time to 20.67 N/mm^2 at 120 days to meet the design strength of concrete. It is therefore recommended that the CCA could be used up to 10% ash addition in concrete for load bearing structure and at 20% for lightweight concrete structure.

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