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DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING

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1. *M. A. Salau, *O. J. Oseafiana and Oyegoke (2015) "Effects of Elevated Temperature on Concrete with Recycled Coarse Aggregates", 2nd International Conference on Innovative Materials, Structures and Technology, IOP Conf. Series. Paper 012078

2. *M. A. Salau *and A. O. Busari (2015 "Effect of Different Coarse Aggregate Sizes on the Strength Characteristics of Laterized Concrete", 2nd International Conference on Innovative Materials, Structures and Technology, IOP Conf. Series. Paper 012079

3. E. E. Ikponmwosa, *M. A. Salau* and W. B. Kaigama "Evaluation of Strenght Characteristics of Laterized Concrete with Corn Cob Ash (CCA)", 2nd International Conference on Innovative Materials, Structures and Technology, IOP Conf. Series. Paper 012009

4. K. B. Osifala, *M. A. Salau *and A. A. Adeniyi "Effect of Waste Plastic Shreds on Bond Resistance between Concrete and Steel Reinforcement", 2nd International Conference on Innovative Materials, Structures and Technology, IOP Conf. Series. Paper 012051

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Evaluation of Strength Characteristics of Laterized Concrete with Corn Cob Ash (CCA) Blended Cement

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Evaluation of Strength Characteristics of Laterized Concrete with Corn Cob Ash (CCA) Blended Cement

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Abstract: Agricultural wastes are dumped in landfills or left on land in which they constitute nuisance. This study presents the results of investigation of strength characteristics of reinforced laterized concrete beams with cement partially replaced with corn cob (agricultural wastes) ash (CCA). Laterized concrete specimen of 25% laterite and 75% sharp sand were made by blending cement with corn cob ash at 0 to 40% in steps of 10%. A concrete mix ratio of 1:2:4 was used to cast 54 cubes of 150x150x150mm size and 54 beams of dimension 750x150x150mm.

The results show that the consistency and setting time of cement increased as the percentage replacement of cement with CCA increased while the workability and density of concrete decreased as the percentage of CCA increased. There was a decrease in compressive strength when laterite was introduced to the concrete from 25.04 to 22.96N/mm^2 after 28days and a continual reduction in strength when CCA was further added from 10% to 40% at steps of 10%. Generally, the beam specimens exhibited majorly shear failure with visible diagonal cracks extending from support points to the load points. The corresponding central deflection in beams, due to two points loading, increased as the laterite was added to the concrete mix but reduced and almost approaching that of the control as 10% CCA was added. The deflection then increased as the CCA content further increased to 20%, 30% and 40% in the mix. It was also noted that the deflection of all percentage replacement including 40% CCA is less than the standard recommended maximum deflection of the beam. The optimal flexural strength occurred with 10% CCA content.

1. Introduction

The high costs of procuring concrete materials for construction have over the years made the users to compromise quality, resulting in series of collapsed buildings and loss of properties in developing countries. Agricultural by-product pozzolans have been used in the manufacture and application of blended cements [1].

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Corn cobs are wastes which are dumped in large quantities during corn season and they impose hazard to the environment in terms of their unpleasant odour and unsightly appearance in open dumps, located in most cities of Nigeria.

Adesanya and Raheem [2] studied the use of CCA blended cement produced in the controlled environment of a factory, to produce concrete specimens. Ettu et al. [3] studied the strength of binary blended cement composites containing corn cob ash. Both studies concluded that the compressive strength of the CCA-blended cement concrete is lower than that of plain concrete (the control) at early curing ages but improves significantly at later ages (after 90 days). Thus, it is important to look for ways of increasing the strength at early ages. Raheem et al. [4] studied the effects of admixtures on the properties of corn cob ash cement concrete. They opined in their results that the incorporation of admixtures in corn cob ash cement concrete generally increases its workability and compressive strength at all ages, irrespective of the type used. Adesanya and Raheem [5] studied the permeability and acid attack of corn cob ash blended cements and concluded that the resistance to chemical attack (HCl and H_2SO4) was improved with the addition of up to 15% CCA. Additionally, Binici, et al. [6] showed that an increase in ash content caused a significant increase in the sodium sulphate resistance of the concrete. This was further buttressed by Binici, et al. [7] that the resistant to sulphate attack was as a result of the more condensed physical structure of CCA compared to that of Portland cement which was shown by microscopic analysis.

Udoeyo et al. [8] investigated some characteristics of concrete containing laterite as partial or full replacement of sand aggregate. They opined in their results that concrete with up to 40% replacement level of sand with laterite could attain design strength of 20N/mm^2. Hence, they concluded that it is possible to use laterite as replacement for sand in concrete up to 40% replacement level. Oluseyi [9] studied the influence of weather on the performance of laterized concrete. The simulation of weathering condition (wet & dry) was carried out by conditioning laterized concrete cubes to varying temperature and alternate wetting and drying. The results of the investigation showed that generally, the compressive strength of laterized concrete decreases when subjected to alternate wetting and drying. However, he concluded that laterized concrete with a laterite-granite fine ratio of between 40 and 60% conditioned to a temperature range of 75-125^{o}C attained compressive strengths up to 22.52N/mm^2. This is without the use of Portland cement and there was no addition of any pozzolan.

The current work aims at investigating the strength characteristics of laterized concrete with cement partially replaced by corn cob ash, in view of the fact that laterized concrete and corn cob ash have been established as cost-saving concrete and pozzolan respectively. Also, no known studies to our knowledge, is available on this study.

2. Experimental procedure and methodology

For the constituents of the laterized concrete, the cement was ordinary Portland cement with the properties conforming to the British Standard, BS12 with an average bulk density of about 1297.5 kg/m^3. The coarse aggregate was crushed granite, density of 2460 kg/m^3 with 12mm maximum diameter while the fine aggregate was made up of 75% sharp sand, obtained from an upland river bed and 25% laterite fine, dug from the ground around Ikorodu town, Lagos State, Nigeria. The samples of the aggregate were obtained in accordance with BS1377-1 while the tests on them, reported in table 1, were carried out in accordance with BS 1377-2. The water used was clean, portable and free from impurities. Corn Cob Ash (CCA) was obtained by burning the corn cob in an open drum. Chemical composition and other properties of the corn cob ash (CCA) and cement were determined, to ascertain the pozzolanic or cementitious properties of the materials respectively.

The percentage replacement of cement with corn cob ash was varied in steps of 10% up to 40%. A concrete mix ratio of 1:2:4 (cement/CCA : fine aggregate : coarse aggregate) by weight with water/cement ratio of 0.65 was adopted throughout this work. The normal concrete specimens, that is without laterite and corn cob ash, served as the first control while laterized concrete without CCA was used as the second control for the experiment. The test specimens were rectangular beams of 150 x 150mm in cross-section and 750mm long. Longitudinal reinforcement was provided in the beams. Specimens of each type of concrete mix were prepared in batches of three beams. Three 150mm cubes were also cast with each batch of the beam. The cubes were immersed in water for 7, 14 or 28 days, as appropriate, at the end of the period they were removed and allowed to drain for 2 hours, prior to testing. The beams were cured under damp sand for 3days and kept in the laboratory until the testing age of 45 days, 60 days and 90 days.

The beams were tested on a simply supported span of about 690mm under symmetrical two-point loading in increment of 5 kN using Avery Denison testing machine with maximum capacity of 8500 kN while the cube crushing tests were performed on ELG Budenberg compression machine with maximum capacity of 1560 kN. Dial deflection gauge was placed at mid-span of bottom face of the beam and readings were taken before and after every load increment. During testing, the development of crack, mode of failure, final failure load and central deflection at the ultimate load were noted and recorded for every specimen tested.

3. Results and discussion

3.1. Chemical composition of corn cob ash

Results of chemical composition tests carried out on corn cob ash (CCA) and cement are shown in table 1.

Table 1. Chemical composition of sieved corn cob ash (CCA) and ordinary portland cement (OPC).

Oxides (%)	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	Na_2O	K_2O	SO_3	C	LOI
CCA	6.70	44.60	1.42	0.025	0.004	0.050	0.30	0.004	46.73	0.160
OPC	63.58	19.05	4.98	0.64	1.96	0.75	0.43	0.50	0.00	0.018

The results show that the corn cob ash has low CaO content and relatively high SiO_2 content, when compared with cement. Large quantity of carbon was recovered as residue from CCA and thus, CCA can be classified as a pozzlan, according to ASTM C618-12a.

The results obtained indicate that the CCA contained silicon dioxide content of 44.6% which is greater than the recommended minimum requirement of 25% according to BS EN 197-1(2000). The total silicon dioxide, iron oxide, and aluminium oxide (SiO_2+Fe_2O_3+Al_2O_3) content is 46.05%. This value is noted to be slightly below the code (ASTM C618–12a) requirement of 50% minimum for a class C pozzolan. The SO_3 content is 0.004 which is below the maximum value of 4.0% as specified for class C pozzolan; according to ASTM C618-12a. The loss on ignition (0.16) is also below the maximum allowable (6.0) specified. Thus, corn cob ash can be said to be a pozzolan of class C on the basis of its chemical composition. The high carbon content of about 47% could be considerably reduced if the process of combustion (incineration) is improved.

3.2. *Physical properties of cement, corn cob ash and aggregates*
The physical properties of different concrete materials are summarized in table 2.

Table 2. Summary of physical properties of cement, corn cob ash and aggregates.

Tests	Cement	Corn Cob Ash	Granite	Sharp Sand	Laterite
Moisture Content (%)	0.02	0.25	0.75	6.42	13.48
Water Absorption Capacity (%)	-	-	1.22	16.34	20.11
Specific Gravity	3.08	2.18	2.46	2.56	2.59
Dry Density (kg/m3)	3080	2180	2460	2560	2590
Bulk Density (kg/m3)	1298	923	2478	2724	2939
Coefficient of Uniformity (Cu)	-	-	1.51	3.07	4.55
Coefficient of Curvature (Cc)	-	-	1.07	1.31	1.86
Fineness Modulus (FM)	-	-	2.85	4.09	3.29

The moisture content of granite used was 0.75% while that of sharp sand and laterite were 6.42% and 13.48% respectively. These show that laterite was more saturated than sharp sand by about 7.06%. This moisture content was taken into consideration during the mix design.
The results of sieve analysis and other preliminary tests on the concrete constituent materials, as shown in table 2, indicate that all the fine and coarse aggregates are uniformly graded in accordance with ASTM D2487-11.

3.3. *Effect of CCA on workability of concrete*
For the consistencies, initial and final setting time tests for all percentage replacements of cement in concrete with CCA were carried out. It is observed that as the percentage replacement of cement with CCA increases, the initial setting time approached the final setting time. The initial setting time increased from 1 hour 33 minutes at control (0% CCA, 0% laterite) to 5 hours 21 minutes at 40% (40% CCA, 25% laterite) replacement level, while the final setting time increased from 2 hour 48 minutes at control (0% CCA, 0% laterite) to 6 hours 23 minutes at 40% (40% CCA, 25% laterite) replacement. However, BS EN 197-1:2000 requirement of 45 minutes minimum initial setting time and maximum of 10 hours final setting time, were met by all the percentage replacement levels. It is concluded that CCA has a retarding effect on concrete; hence, it could be used to delay/retard hydration process in pre-mix concrete requiring transportation to site as well as in arid environment.

The results of slump test carried out on fresh concrete showed that the control mix has the highest average workability value of about 87mm for the 3 batches and could be described as true slump; and the values gradually decreased to 79mm as soon as laterite was added to the mix, but still remained true slump. As corn cob ash was further introduced into the mix at steps of 10% up to 40%, the slump decreased sharply from 79mm to a minimum value of 42mm (for 40% CCA concrete); the type changing from true to shear slump. This could occur as a result of larger surface area, occasioned by the addition of CCA which demanded more water from the mixes; resulting in stiffer concrete with reduced workability

3.4. *Effect of CCA on the density and compressive strength of concrete*
It can be deduced from table 3 that the normal concrete (0% laterite, 0% CCA) has an average density of about 2445kg/m^3 for all curing ages and there was no significant change in density (from 2445kg/m^3 to 2455kg/m^3) when laterite was added to the mix. When CCA was further introduced to

the mix, density of the cubes decreased to a 2248kg/m^3 (about 8% reduction) for 25% laterite; 40% CCA concrete. This could be due to the fact that CCA has a lower specific gravity than ordinary Portland cement. However, all the density values are within the limit of normal weight concrete (2000-2600kg/m^3), in accordance to BS EN 206-1 (2000).

Table 3 shows that the compressive strength of all the replacements increased with increase in curing age. This is expected just like in normal concrete. Also, there was an insignificant decrease in compressive strength when laterite was introduced into the concrete mix from 19.26 to 17.63N/mm^2, 22.07 to 20.44N/mm^2 and 25.04 to 22.96N/mm^2 for 7 days, 14 days and 28 days respectively. There was a continuous reduction in strength when corn husk ash was further added to the mix from 0-40% at steps of 10% with 40% giving the least strength (8.59N/mm^2, 11.26N/mm^2 and 13.48N/mm^2 for 7 days, 14 days and 28 days respectively) for all the curing ages. The reduction in strength with the introduction of the ash is connected with the low content of CaO and the compound of (SiO_2 + Fe_2O_3 + Al_2O_3).

However, according to ASTM 39, the minimum required compressive strength of concrete to be used for structural purposes is 17N/mm^2. All the percentage replacement levels of cement with CCA, with the exception of 40% (CCA blended concrete) passed the limit. Therefore up to 30% CCA blended cement can be used to make concrete for structural works, depending on the requirements and function of the structure, while 40% CCA blended cement with compressive strength less than 17N/mm^2 can be recommended for non-structural works like blinding, mass concrete filling, etc.

Table 3. Summary of densities and compressive strengths for test samples.

		Percentage replacement of CCA					
	Curing Age (Days)	Normal Concrete	Latetrized Concrete	10% CCA (Laterized)	20% CCA (Laterized)	30% CCA (Laterized)	40% CCA (Laterized)
Density (kg/m^3)	7	2449	2473	2405	2389	2358	2277
	14	2455	2452	2431	2377	2345	2253
	28	2430	2440	2424	2391	2311	2215
	Average	2445	2455	2420	2386	2338	2248
	7	19.26	17.63	14.17	11.85	10.07	8.59
	14	22.07	20.44	18.52	17.33	14.96	11.26
	28	25.04	22.96	21.48	20.15	17.19	13.48

3.5. Strength activity index (SAI)

The strength activity index (SAI) is a measure of the pozzolancity of supplementary cementitious material (SCM) and is measured as the strength relative to the control (laterized concrete), in percent.

Table 4. Strength activity index (SAI) of CCA laterized concrete.

CCA Percentage Replacement of Cement & Sand	Compressive Strength (N/mm2) – SAI (%) Curing Age (Days)		
	7 Days	14 Days	28 Days
0% CCA; 25% Laterite	17.63 – 100	20.44 – 100	22.96 – 100
10% CCA; 25% Laterite	14.17 – 80.15	18.52 – 90.61	21.48 – 93.55
20% CCA; 25% Laterite	11.85 – 62.21	17.33 – 84.78	20.15 – 87.76
30% CCA; 25% Laterite	10.07 – 57.12	14.96 – 73.19	17.19 – 74.87
40% CCA; 25% Laterite	8.59 – 48.72	11.26 – 50.09	13.48 – 58.71

For SCM to be classified as pozzolan, the strength of the blended cement at 7-days and/or 28-days must not be less than 75% of the strength of the control concrete (ASTM C 618-08).

Table 4 shows that at 7 days curing age, lateritic concrete with 10% CCA met the 75% strength of normal laterized concrete with an SAI of about 80.15%. At 14 and 28 days curing ages, apart from lateritic concrete with 10% CCA, the 20% CCA lateritic concrete also met the 75% minimum permissible limit with SAI values of 84.78% and 87.76% at14 days and 28 days respectively. This indicates that laterized concrete and even normal concrete could accommodate CCA as pozzolan. It can be concluded that up to 20% CCA replacement of cement could be used for normal concrete production.

For 30% and 40% CCA replacements of cement in laterized concrete, the SAI for all the ages were below 75%. It was observed that there was no appreciable increase in the SAIs for these replacement levels with increase in age. Thus, 30% and 40% CCA replacement of cement are not recommended for use where strength is a criterion, but can be used for non-structural members like blinding, mass concrete filling, block filling etc.

3.6. Effect of CCA on the flexural strength of beam

Table 5 shows test results of steel reinforced concrete beam specimens under flexural loading with different percentages of CCA.

Table 5. Characteristics in flexure of steel reinforced CCA blended concrete beams.

Composition and Percentage (%) of CCA in Concrete	Beam Characteristics					
	Curing Age (Days)					
	45		60		90	
	Failure Load (kN)	Deflection (mm)	Failure Load (kN)	Deflection (mm)	Failure Load (kN)	Deflection (mm)
Normal Concrete (0% laterite, 0% CCA)	220	1.43	240	1.56	250	1.34
Laterize Concrete (25% laterite, 0%CCA)	190	1.73	220	1.94	230	1.59
Laterize Concrete (25%laterite, 10% CCA)	210	1.57	230	1.59	250	1.43
Laterize Concrete (25% laterite, 20% CCA)	180	1.52	210	1.68	220	1.63
Laterize Concrete (25% laterite, 30% CCA)	170	1.55	180	1.58	200	1.52
Laterize Concrete (25% laterite, 40% CCA)	170	1.67	180	1.70	200	1.69

Analysis of test results of the specimens showed that the flexural strength of the beams at 45-, 60- and 90-day curing ages vary with percentage of CCA in the laterized concrete.

For the normal reinforced concrete beams tested (0% CCA; 0% laterite) at 45, 60 and 90 days, table 5 shows that the failure loads are 220, 240 and 250 kN respectively. This indicates a gradual improvement in load bearing performance with curing age. On the addition of 25% Laterite to the concrete mix, the load carrying capacity of the beams decreased to 190, 220 and 230 at 45-, 60- and 90-day curing ages respectively, with corresponding higher values of deflection for identical load levels. The deflection of laterized concrete beam increased generally at all the curing ages.

For reinforced concrete beams having 25% Laterite fines and 10% - 40% CCA at steps of 10%, and cured at 45, 60 and 90 days, results of experiment showed that the failure loads for the beams decreased with increase in percentage of CCA in the mix for all curing ages. Relative to load sustained, the deflection values of the CCA-cement blended samples were quite high at early curing stages but improved considerably in load bearing capacity at an optimum replacement level of 10% addition of CCA as observed for 45, 60 and 90 days curing ages (table 5). The addition of corn cob ash considerably reduced deflection optimally at 10%. The result at 90 days curing age, when the strength became reasonably steady, further confirms the characteristics of a good pozzolan in the material as it helped the concrete to have considerable high strength at that age.

This suggests that the chemistry of interaction of the pozzolanic content of the ash served as an improvement on the load bearing capacity of concrete, irrespective of the addition of laterite. However, there was gradual increase in load bearing capacity, as well as reduced deflection as soon as cement was replaced with CCA at 10%. Addition of 20%, 30% and 40% CCA led to increase in deflection at lower load values for all curing ages. Thus, it can be deduced that 10% gave the optimal as compared to 20-40% replacement levels of cement with CCA.

3.7. Deflection characteristics of the beams.

Figure 1 shows a typical load–deflection curve for beam specimens with and without CCA content at 90-day curing age. This figure bears resemblance with the behaviour of beam specimens having the same composition of materials at 45- and 60-day curing ages.

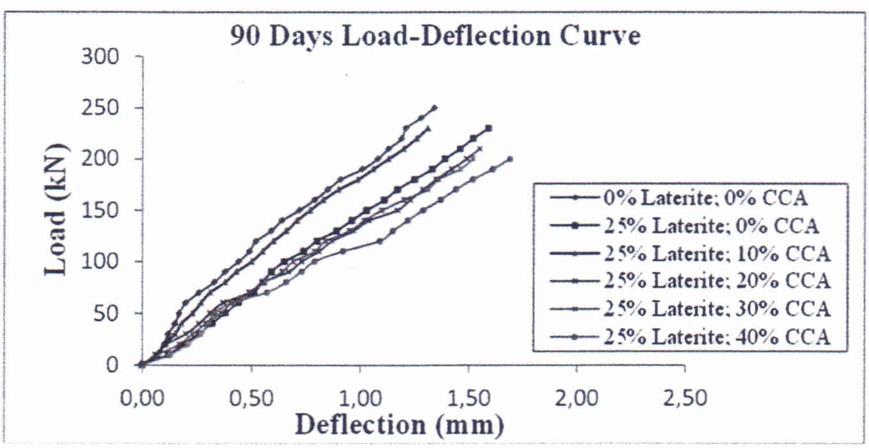

Figure 1. Summary of Load–Deflection Curve for 90 days curing age.

The deflection values were observed at the dial gauge, positioned mid-span of the beam specimens. The observed central deflection exhibited by the beams for different compositions of the materials in the concrete shows similarity in trends.

From Figure 1 above, it is generally observed that deflection increases with increase in CCA content in the concrete mixes irrespective of the curing age. In the same vein, the deflection in laterized concrete without CCA content was observed to be more than the deflection in the laterized concrete mix with 10% CCA content. Generally, for every load applied and at every curing age, plain concrete gave the least deflection before failure. Also, it was observed that for each load case and at predetermined value of loading, deflection reduces with curing age of concrete (which results in increase in strength of concrete), suggesting that the strength of concrete in the beam specimens helps to improve resistance of the beams to flexural loading and deformation.

3.8. Crack pattern and mode of failure

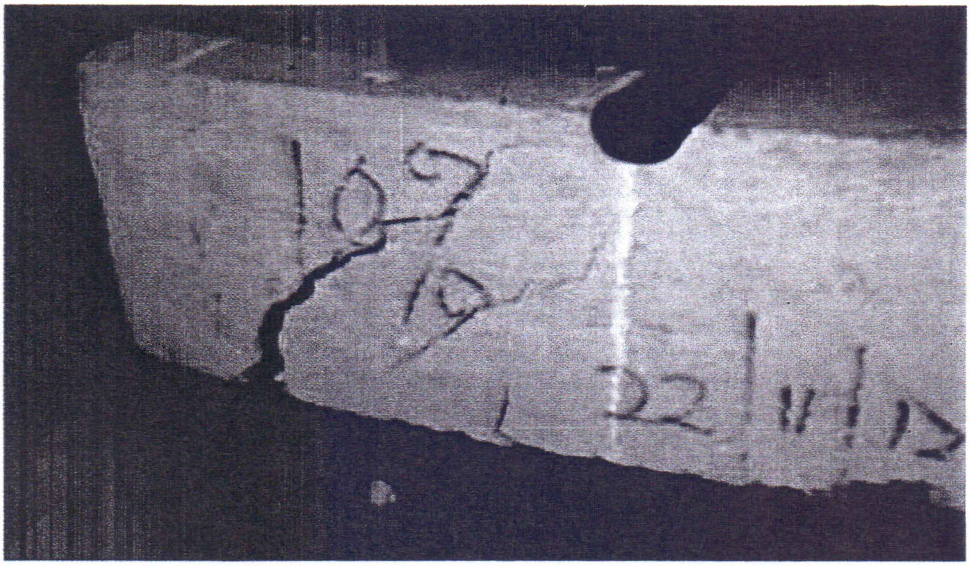

Figure 2. Shear compression failure of a typical beam specimen during flexural test.

Figure 2 shows a typical crack pattern and failure mode of the beams. The specimens had major diagonal shear failure cracks, extending from the supports to the load points in the 2-point load setup.

Largely, the cracks initiated from the tension face of the beams at the supports and propagated rapidly and diagonally toward the load points on the compression zone (compression face) as loading increased. Almost in all cases, the crack patterns were similar. The cracks were observed to widen as applied load increased. Generally, the failure mode of the beams was by shear as shown by the diagonal cracks and to a lower extent, by crushing of concrete on the compression face of the beams. This could be termed 'Shear-Compression Failure' and the cracks referred to as 'Shear-Flexural Cracks'.

4. Conclusion

From the results of the various tests performed, the following conclusions can be drawn:

1. Setting time and consistency of cement increases as percentage replacement of CCA increases. This signifies a retarding property of CCA.
2. Workability of fresh concrete reduces as percentage of percentage of CCA increases. Therefore more water will be required to get workable concrete mixes.
3. The compressive strength of laterized concrete with CCA at all replacement levels increases with increase in curing age which buttresses the fact that compressive strength increases with increase in curing age. Also there was a decrease in compressive strength when laterite was introduced to the concrete mix and a continual reduction in strength when CCA was further added to the mix.
4. The corresponding deflection due to two points loading increases as the laterite is added to the concrete mix but reduces and almost approaching that of the control as 10% CCA is added, before increasing as 20%, 30% and 40% CCA are further added to the concrete mix.
5. Concrete made with 10% CCA has the optimum flexural and compressive strength compared to other replacement levels of CCA and can thus be recommended for use in low cost housing construction.

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