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Flexural Performance of Self-Compacting Concrete Containing Corn-Cob Ash

Oladipupo S. Olafusi*, Adekunle P. Adewuyi, Alex F. Adisa, Obanishola M. Sadiq, Olubayo T. Olateju

Abstract—**The use of supplementary cementitious materials (SCMs) in Self-compacting concrete (SCC) is becoming popular in civil engineering research and developments. This is mostly due to the enhanced rheological characteristics and economic benefits influenced by the inclusion of these SCMs in SCC works. This study experimentally investigated the flexural performance and deformation characteristics of self-compacting concrete (SCC) containing corn-cob ash (CCA). A total of twelve SCC mixes were investigated - eight mixes of CCA blended SCC containing admixtures and two non-CCA blended-SCC mixes with and without admixtures were studied and flexural behavior of 150 × 150 × 600 mm reinforced concrete beam specimens investigated. Although, the control SCC had higher ultimate failure load than the CCA blended SCC, failure loads of all the mixes increased with increased water-binder ratio and CCA blended SCC had better durability properties in first crack development than the control SCC, and their flexural stiffness reduced with increased CCA content. All tested beam specimen failed in shear.**

Keywords— **Self-compacting concrete, corn cob ash, first crack load, ultimate failure load, modulus of rupture, deflection**

I. Introduction

Civil engineering practice and construction works around the world depend to a very large extent on concrete; which is the most versatile heterogeneous construction material and the impetus of infrastructural development of any nation [1]. The overall sustainable economic growth, productivity, and well-being of a nation depend heavily on the functionality, reliability, and durability of its construction facilities [2]-[3]. Aside structural deterioration due to variability in environmental and operational conditions of building and civil infrastructure, the quality of the constituent materials accounts for many cases of structural deficiencies and functional obsolescence recorded in the built environment [4]-[5]. Self-compacting concrete or self-consolidating concrete (SCC) which is characterized as a highly flow-able, non-segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation [6] have been reported to show significant enhancement of strength and stiffness compared to the conventional concrete. Utilization of locally available materials and agro-allied wastes as supplementary cementitious materials in SCC mixes has also been found to enhance the economic power of rural dwellers while simultaneously mitigating the challenges of solid waste management. The usage of mineral admixtures in the production of SCC has successfully and appreciably enhanced the rheology and strength properties of SCC [6]-[18]. It also reduces thermally-induced cracking of concrete due to heat of hydration, increases workability and long-term properties of concrete and reduces the high cost of SCC production per cubic meter [7]-[20]. Although, several research works have been carried out and reported on the performance of pozzolanic materials for use in concrete [12, 21-27], their findings indicated that strength properties decreased marginally with increased pozzolanic contents, while [23] indicated improved flexural strength with the use of rice husk ash in self-compacting concrete. This study investigated the flexural behavior of steel reinforced SCC beams containing CCA as a partial replacement for cement.

Oladipupo S. Olafusi* (Corresponding Author), Adekunle P. Adewuyi, Alex F. Adisa, Olubayo T. Olateju

College of Engineering / Federal University of Agriculture, Abeokuta Nigeria.

Obanishola M. Sadiq

Civil and Environmental Engineering / University of Lagos Nigeria

II. Materials and Methods

A. *Materials*

Cement: Ordinary Portland cements (32.5 grades) conforming to BS 12 [28].

Water: Portable water from municipal supplies was used in the study.

Fine aggregate: Uniformly graded sharp river sand with coefficient of uniformity, C_u of 2.29, coefficient of curvature, C_c of 1.51, effective size of 0.35 mm and fineness modulus of 2.38.

Coarse aggregate: Uniformly graded crushed granite conformed to BS 882 [29] with coefficient of uniformity, C_u of 1.38; coefficient of curvature, C_c of 1.14; effective size of 8 mm and fineness modulus of 2.91.

Corn cob ash (CCA): Corn cobs ash was sourced from the incineration of corn cobs at temperature range 625–650˚C. The well graded CCA had coefficient of uniformity, C_u of 1.29; coefficient of curvature, C_c of 1.29; effective size of 0.09 mm; fineness modulus of 1.86 and specific gravity of 3.49. The chemical composition of the ash had the sum of silicon dioxide, aluminum oxide and ferric oxide (SiO_2 + Al_2O_3 + Fe_2O_3) as 64.58%, thus classified CCA as class C pozzolanic material according to ASTM C618-08 [30].

Admixture: Conplast SP430 Superplasticizers (a chloride free, super plasticising admixture based on selected sulphonated naphthalene polymers) were used in this research. Previous research studies showed that superplasticizer can be used to achieve good workability. The high flowability is achieved by using superplasticizer, while segregation resistance was either achieved by using large quantity of fine materials or appropriate VMA [31-35]. The particle size curve for the CCA and aggregates used for this study are presented on figure 1.

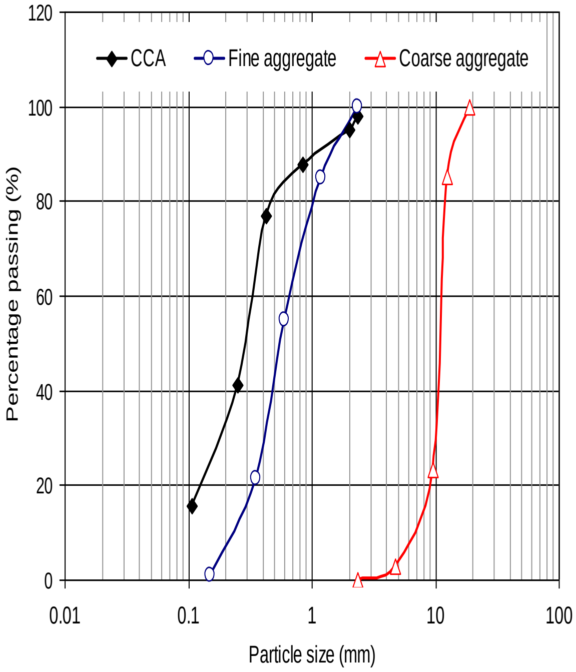

Figure 1. Particle size curve for CCA and Aggregates

B. *Experimental Procedure*

Thirty six specimens of 150 × 150 × 600 mm reinforced concrete beams were produced from twelve SCC mix samples as presented in Table 1. Six mixes were varied at 0.38 and 0.40 water-binder ratios. All samples had 2 L/100 kg dosage of water-reducing admixture except K and L without admixture. Samples A and B served as the control SCC samples with 0% CCA replacement for cement. Samples C and D had 5% CCA blended SCC, samples E and F had 10 % CCA-blended SCC, samples G and H had 15% CCA-blended, samples I and J had 20% CCA-blended, while samples K and L had 0% CCA blended SCC similar to samples A and B but without water reducing superplasticisers. The 28-day cylinder compressive strengths (f'c) of the mixes from previous research, water cement ratio (w/c), Corn Cob Ash (CCA), Cement, Fine Aggregate (FA), Coarse Aggregate (CA) and superplasticiser proportions are presented on table 1. The beams were reinforced with two bars of 10 mm dia. high yield steel each at the tension and compression zones with 8 mm dia. shear links spaced at 150 mm as shown in Figure 2. The samples were prepared under standard laboratory conditions, water-cured by immersion and tested after 28 days using a hydraulic jack and dial gauge apparatus with the four-point loading flexural test setup as shown in Figure 3. The supported span for the flexural test setup was 450 mm while the loading span was 225 mm (i.e. ½ of the supported span); and the moduli of rupture (M.R.) were estimated using [36] below;

$$M.R. = 3P_uL/4bd^2$$

Where,
P_u is the ultimate failure loads of the beam specimen
L is the length of the supported span
b = Breadth of the beam specimen
d = depth of the beam specimen
The average values of flexural strength for three specimens were computed for the SCC mixes.

TABLE I. Mix proportions for the CCA blended SCC

Sample	f'c	w/c	Cement (kg/m^3)	CCA (kg/m^3)	F.A (kg/m^3)	C.A (kg/m^3)	SP (Litres per 100kg cement)
A	21.03	0.38	500	0	890	875	2
B	18.23	0.40	500	0	890	875	2
C	18.43	0.38	475	25	890	875	2
D	17.39	0.40	475	25	890	875	2
E	20.25	0.38	450	50	890	875	2
F	18.15	0.40	450	50	890	875	2
G	19.47	0.38	425	75	890	875	2
H	17.49	0.40	425	75	890	875	2
I	19.26	0.38	400	100	890	875	2
J	17.28	0.40	400	100	890	875	2
K	20.20	0.38	500	0	890	875	0
L	18.28	0.40	500	0	890	875	0

Figure 2. SCC beam specimen preparation

Figure 3. Flexural test of SCC beam specimens

III. Results and Discussions

Table 2 shows the results of flexural examinations in terms of the first crack load, P_{cr}, ultimate failure load, P_u and the modulus of rupture, M.R.

The results showed that sample A had the highest modulus of rupture (M.R.) of 14.84 N/mm^2 while sample I had the lowest M.R. of 8.07 N/mm^2. Although, previous research showed that compressive strengths of the mixes increased with reduced water binder ratio as shown on table 1; the failure loads and M.R. of the tested beams except the control specimen increased with increased water-binder ratio as CCA reduced.

Fig. 4 shows that failure patterns were similar for all the SCC beam specimen examined, as they all had a shear failure pattern (diagonal cracks). The first crack noted on CCA blended SCC beam was in the range 31-57% of their ultimate failure loads while the first crack loads of beam specimens without CCA were less than 26% of their ultimate failure loads as shown in fig. 5. This implies that the CCA blended SCC beams possess better durability potentials in first crack developments than SCC beams without CCA incorporation. However, substantial percentage of the load carrying capacity of the former may have exhausted at first crack in line with previous assertions [2].

Fig. 6 shows the load-deflection (P-δ) behaviour of the beam specimens containing CCA, which indicated that samples C and D with 5% CCA replacement had better stiffness properties similar to samples A, B, K and L (the mixes without CCA content), than other beam specimen containing CCA. The control specimen had the highest stiffness property. The mixes containing CCA in excess of 5% replacements had similar P-δ curve, and their stiffness reduced as CCA content increased. This indicates that increased CCA content reduces the stiffness of SCC beams containing CCA.

TABLE II. Results of Flexural Examinations

Sample	Density (Kg/m^3)	P_{cr} (KN)	P_u (KN)	P_{cr}/P_u	M.R. (N/mm^2)	Mode of Failure
A	2000	30.00	148.38	0.20	14.84	Shear
B	1976	33.33	132.71	0.25	13.27	Shear
C	2000	28.33	91.86	0.31	9.19	Shear
D	2025	31.67	96.97	0.33	9.70	Shear
E	1926	40.00	82.81	0.48	8.28	Shear
F	1926	47.67	83.48	0.57	8.35	Shear
G	1926	39.67	82.55	0.48	8.26	Shear
H	1926	42.33	83.30	0.51	8.33	Shear
I	1879	24.67	80.67	0.31	8.07	Shear
J	1901	29.00	82.50	0.35	8.25	Shear
K	1988	25.67	103.88	0.25	10.39	Shear
L	2025	28.00	109.99	0.25	11.00	Shear

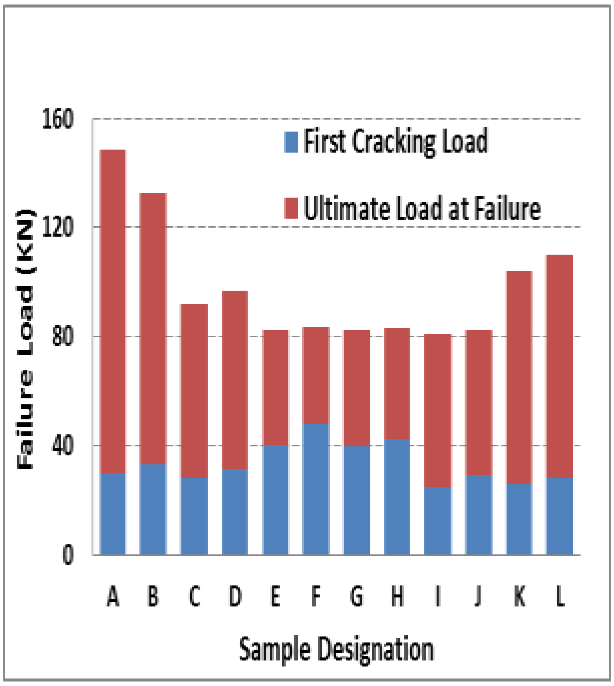

Figure 5: Crack development in SCC beams

Figure 4. Failure pattern of tested SCC beams

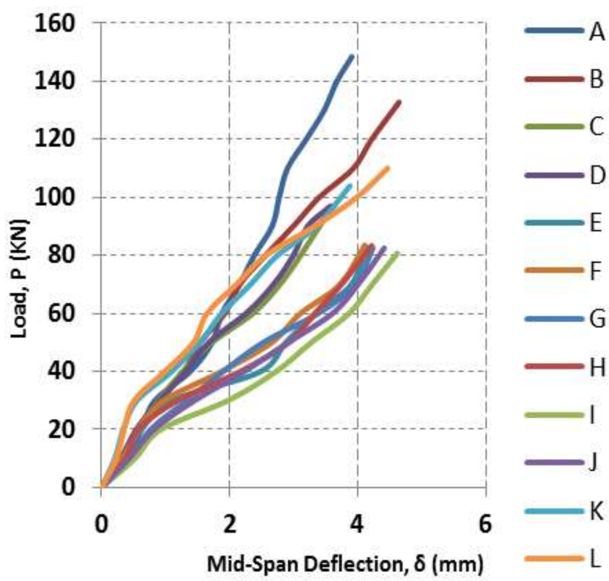

Figure 6: Load-deflection curve

IV. Conclusions

The following conclusion can be drawn from the study:

1. The modulus of rupture of SCC beams containing CCA increased with increased water-binder ratio and reduces with increased CCA content.
2. Although, SCC beams containing CCA tend to possess a reduced post-first crack loading capacity; SCC beams containing CCA exhibited more durability potentials in first crack development than SCC specimens without CCA incorporation.
3. Stiffness of SCC beams containing CCA reduces with increased CCA content; while SCC specimens containing 5% CCA have comparable stiffness with the control specimens which can hereby be stated that 5% CCA is the critical amount structurally beneficial.

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About the Authors:

Oladipupo S. Olafusi, *MSc*
PhD candidate of Structural Engineering at the College of Engineering, Federal University of Agriculture, Abeokuta, Nigeria; he has several publications in reputable journals on concrete technology, structural and highway engineering.

Adekunle P. Adewuyi, *PhD*
Senior Lecturer, Civil Engineering, College of Engineering, Federal University of Agriculture, Abeokuta, Nigeria; his research interests cover structural health monitoring-based maintenance, smart materials and structural dynamics, mechanics of concrete structures, time-dependent deterioration prediction of structural systems, and durability assessment of construction materials.

Alex F. Adisa, *PhD*
Senior Lecturer, Agricultural Engineering, College of Engineering, Federal University of Agriculture, Abeokuta, Nigeria; his research interest covers Agric. Machinery development Engineering for various field and industrial operations and has several publications in reputable journals.

Obanishola M. Sadiq, *PhD*
Professor of Structural Engineering, Faculty of Engineering, University of Lagos, Nigeria; his interests cover nonlinear static and dynamic analysis of shell and spatial structures, including modeling and analysis of masts and towers. He is a visiting professor at the College of Engineering, Federal University of Agriculture, Abeokuta, Nigeria.

Olubayo T. Olateju, *PhD*
Emeritus Professor of Construction Technology, Structural and Highway Engineering; an exemplary academia and Howard and Purdue Universities-trained scholar; he authored, co-authored and edited many books and published over 150 papers and technical reports and also supervised various PhD students before his demise on 19th November, 2015.