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Durability Characteristics of Self-Compacting Concrete Incorporating Corn Cob Ash

Egbe-Ngu Ntui Ogork [1], Abdulkarim Muhammad Auwal [2]
[1,2] Department of Civil Engineering,
Bayero University, Kano
Email: egbenguogork@yahoo.com[1], abuiyal1@gmail.com[2]

ABSTRACT
This paper assesses the effects of corn-cob ash (CCA) on the durability of self compacting concrete (SCC). The CCA used was obtained by controlled burning of corn cob to ash in a kiln to a temperature of 600 °C for two hours, and after allowing cooling, sieved through sieve 75 μm and characterized. The effects of CCA on durability of SCC grade 35 were investigated at replacement levels of 0, 5, 10, 15 and 20 %, respectively by weight of cement. A total of sixty number 150 mm x 150 mm x 150 mm cubes of SCC-CCA were tested for compressive strength at 3, 7, 28 and 56 days of curing in accordance with standard procedure. Crushed samples of the cubes of SCC from the compressive strength test at 28 days curing for the five mixes were weighed and exposed in 5 % concentration of sulphuric acid (H_2SO_4) solution and weight retained recorded at 7 days interval until the 28^{th} day, to determine the resistance of SCC-CCA to sulphuric acid aggression. Also, fifteen number 100 mm x 100 mm x 100 mm cubes of SCC-CCA were tested for water absorption at 28 days curing. The results showed that the CCA has a combined SiO_2, Al_2O_3 and Fe_2O_3 content of 71.32%, which can be classified as class F pozzolana. The compressive strength of SCC increased with increased in curing age and decreased with increase in CCA content. The 56 days compressive strength of the CCA-SCC ranged from 30.7 N/mm^2 to 52.1 N/mm^2, and up to 15 % CCA is recommended as partial substitute of cement for production of SCC. CCA decreased the resistance of SCC to sulphuric acid attack compared with control samples (6.27 to 11.29 % reduction) and also increased the water absorption of SCC.
Key words: Corn cob ash, Self compacting concrete, Sulphuric acid attack, Water absorption

INTRODUCTION
Concrete material is one of many materials used in construction field. The strength of concrete is generally regarded as the most important

property to be considered. This is because the strength of concrete can provide an overall picture of the concrete quality. However, it is also important to note that the concrete must withstand the conditions that had been designed, without damage, over a period of years. So, in addition to its strength, it should also have a high durability. The durability of concrete is an important property which significantly determines the service life of concrete structures (Turkel et *al.*, 2007). Durability of concrete is its ability to resist chemical and physical attacks that lead to deterioration of concrete during its service life (Yuksel et *al.*, 2007). These attacks are leaching, sulphate attack, acid attack, carbonation, alkali aggregate reaction, freezing-thawing and abrasion (Ogork, et al, 2014).

Acidic attack usually originates from industrial processes, but it can even be due to urban activity. The behavior of pozzolanic cement to acidic attack has been reported in technical literature without any consistency. According to Zivica et al. (2002), pozzolanic cement has better durability characteristics against acid attacks, but Turkel et al. (2007) claimed otherwise. It was however reported by Ogork et al. (2014) that the resistance to acid attack on pozzolanic concrete varies with the acid in consideration. The acidic attack on pozzolanic cement products is affected by the processes of decomposition and leaching of the constituent of cement matrix (Gutt and Harrison, 1997). Acids react with alkaline components of the binder (calcium hydroxide, calcium silicate hydrates and calcium aluminates hydrates) lowering the degree of alkalinity.

Self compacting concrete (SCC), requiring no compaction work at site or concrete plants was developed in Japan in 1988 to improve the durability and uniformity of concrete (Okamura and Ouchi, 1999). The constituent materials used for SCC are the same as those for conventionally vibrated concrete except that SCC contains a lesser amount of coarse aggregates, a large amount of fine aggregates, the incorporation of pozzolana, a low water-binder ratio, larger amount of OPC and a super plasticizer to enhance workability, and this is what leads to self compatibility. A concrete mix can only be classified as SCC if the requirements for all the three workability properties of filling ability, passing ability and segregation resistance are fulfilled (EFNARC, 2002).

Reports on the performance of SCC to adverse environment when compared with normal concrete have been inconsistent. Mortsell and Rodum (2001), for instance reported that out of a variety of durability tests on SCC and normal concrete, SCC only showed better frost resistance of the skin surface. However, Makishima et al. (2001) study reported excellent resistance of SCC to freezing and thawing, but in order to achieve long-term frost resistance, entrained air is needed. Persson (2003) also found that internal damage is much less in SCC compared to normal concrete, but scaling is similar between SCC and normal concrete. Kayode and Ilesanmi (2015) indicated the high potential of corn cob ash (CCA) on 1: 2: 4 mix concrete incorporating super plasticizer to improve its workability. Ogork and Auwal (2016) also reported that up to 15 % CCA is recommended as partial substitute of cement for production of SCC. This study investigates the effect of corn cob ash (CCA), a pozzolana from agricultural waste, on the durability of SCC.

MATERIALS AND METHODS

Materials

The fine aggregate used is sand from River Challawa, Kano. The coarse aggregate used is crushed granite with a 20 mm nominal size. The particle size distribution of the sand and granite are shown in Figure 1. The specific gravity of the materials is shown in Table 1. Ordinary Portland cement (OPC) (3X Dangote brand) was used. The oxide composition of the OPC is shown in Table 2. The super-plasticizer used is a Conplast SP342 MS, which is a chloride free super-plasticizing admixture based on selected sulphonated naphthalene polymers. It has a specific gravity of 1.19 as specified by the manufacturer.

Corn cob used was sourced from Faculty of Agriculture, Bayero University, Kano. The corn cobs were ground to a maximum size of 4 mm and later burnt in a furnace at a temperature of 600 °C for 2 hours to obtain the ash, which was allowed to cool before sieving through a 75 µm sieve and characterized. The CCA grain size distribution is also shown in Figure 1. A chemical composition analysis of the CCA was conducted using X-Ray Fluorescence analytical method.

Methods

Mix Design of SCC

Concrete grade 35 was designed in according with ACI 211.1 (1991) based on (EFNARC, 2002) guidelines for SCC using a 1: 1.83: 1.73 mix ratio and water cement ratio of 0.4, which was varied according to consistency of cement-CCA paste. Five mixes were used; SCC-00 (control mix) and SCC-05, SCC-10, SCC-15 and SCC-20 are mixes with CCA at replacement levels of 5, 10, 15, and 20 %, respectively of cement content. Conplast SP432 MS super plasticizer was used to maintain high workability.

Compressive Strength Test

The compressive strength test was carried out in accordance with BS EN 12390-3 (2009), using 150 mm x 150 mm x 150 mm cubes of SCC containing CCA of 0, 5, 10, 15 and 20 %, respectively. A total of sixty (60) number cube specimens were cast and cured in water for 3, 7, 28 and 56 days, respectively and at the end of every curing scheme, three samples were crushed using the Avery Denison compression machine of 2000 kN load capacity and at constant rate of 15 kN/s and the average taken.

Test of SCC-CCA Resistance in Acidic Environment

This was carried out using crushed samples of the cubes of SCC from the compressive strength test at 28 days curing for the five mixes. Three pieces of crushed samples for each percentage replacement of CCA were taken and weighed before immersion in 5 % concentration of sulphuric acid (H_2SO_4) medium. At every 7 days interval until the 28th day, the samples were removed, cleaned and left to dry before weighing to obtain the weight retained after the acid degradation.

Water Absorption Test

Water absorption test was conducted on 100 mm x 100 mm x 100 mm SCC cubes in accordance with BS EN 12326-2 (2002). A total of fifteen (15) number samples of concrete were cast and cured for 28 days and weighed before drying in a hot air oven at 105 °C. The drying process was continued, until the difference in mass between two successive measurements at a 24 hour interval closely agreed. The dried specimens were cooled at room temperature and then immersed in water. The specimens were taken out at regular intervals of time, surface dried and weighed. The difference between the saturated mass and the oven dried mass expressed as a percentage of the oven dried mass gives the saturated water absorption. The specimens were tested in triplicate to obtain an average.

RESULTS AND DISCUSSION

Physical Properties of Concrete Constituent Materials

Table 1: Physical properties of constituent materials

Property	Cement	Sand	Crushed granite	CCA
Specific gravity	3.16	2.64	2.70	2.05
Fineness modulus	-	2.8	-	-

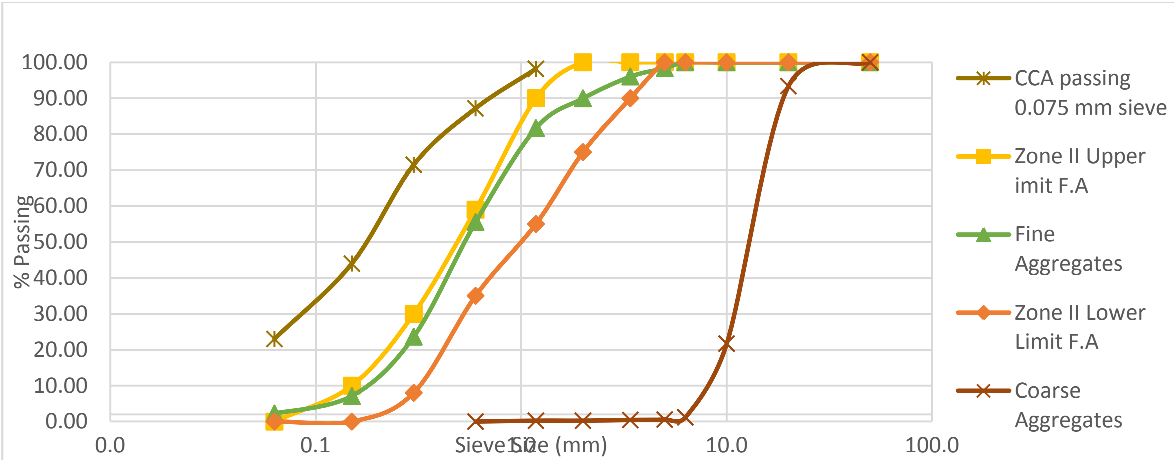

Figure 1: Particle size distribution of CCA, fine and coarse aggregates

The specific gravity of the constituent materials is shown in Table 1, while the particle size distribution curves are shown in Figure 1. The grain size curve indicated that the sand used was classified as zone 2 based on BS 882(1992) grading limits for fine aggregates and was well graded.

Corn Cob Ash (CCA)

Table 2: Oxide composition of OPC (3x Dangote brand) and CCA

Oxide (%)	Si_2O	Al_2O_3	Fe_2O_3	CaO	MgO	ZnO	MnO	CuO
OPC	19.36	3.57	4.32	66.58	0.43	-	0.04	0.021
CCA	49.39	15.24	6.69	8.20	1.11	0.42	0.11	0.071
Oxide (%)	Na_2O	K_2O	P_2O_5	SO_3	TiO_2	Cr_2O_3	V_2O_5	LoI
OPC	-	0.615	-	1.78	0.23	-	0.02	2.98
CCA	6.04	5.40	4.37	2.39	0.53	0.028	0.004	3.13

The result of chemical analysis of CCA shown in Table 2 shows that the CCA has a combined silicon dioxide, iron oxide, and aluminium oxide content of 71.32 %, consistent with works of Adesanya and Raheem (2007). This value is noted to be slightly above the minimum of 70% requirement given in ASTM C 618 (2008) for a class F pozzolana. The SO_3 content is 2.39 % which is below the maximum value of 5.0 %

as specified. The chemical composition of the cement is satisfactory and has met the requirements of BS EN 197, Part 1 (2000) standard.

Compressive Strength of SCC-CCA

The compressive strength of SCC containing CCA shows increase in strength with increase in curing age and decrease in compressive strength with increase in CCA content as shown in Figure 2. The increase in strength with curing age may be attributed to the cementing products formed as a result of hydration of OPC and also from pozzolanic reaction of lime and CCA (Adesanya and Raheem, 2010). The decreased in strength with increase in CCA content may be due to the dilution effect of OPC and formation of weaker C-S-H gel as a result of pozzolanic reaction of CCA, consistent with Ogork *et al.* (2014). The 56 days compressive strength of the SCC ranged from 30.7 N/mm^2 to 52.1 N/mm^2, with least strength at 20 % CCA content and highest strength at 0 % CCA (control). It is recommended that up to 15 % CCA be used as partial substitute of cement in SCC.

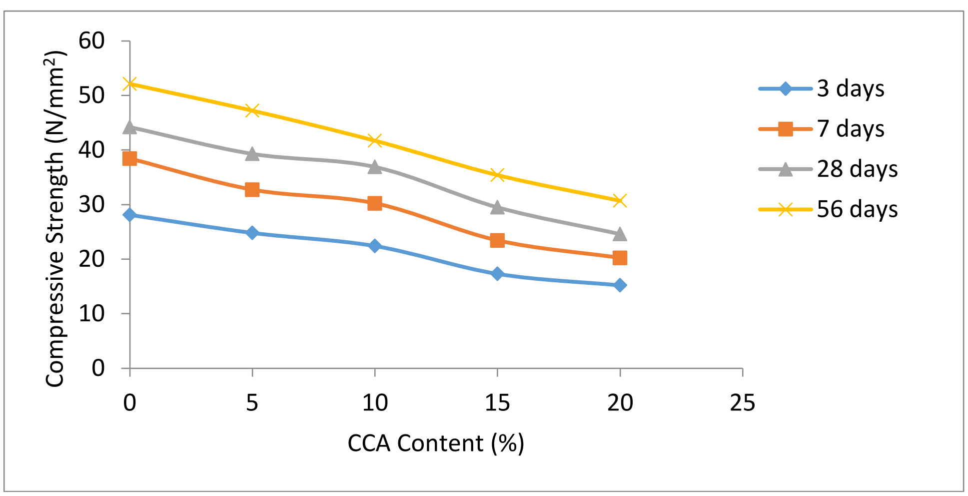

Figure 2: Compressive strength of SCC-CCA.

Resistance of SCC-CCA to Sulphuric Acid Attack

Figure 3 shows the weight retained of SCC-CCA when immersed in sulphuric acid medium. The weight of SCC retained decreased with increase in exposure duration and also decreased with increase in CCA content. The weight retained after 28 days of exposure in 5 % concentration of sulphuric acid medium ranged from 85.1 % to 96.0 % of the initial weight of the specimens, with SCC containing 20 % CCA having the least weight retained while SCC containing 0 % CCA having the maximum weight retained. This indicated a decrease in resistance of 6.27 to 11.29 % compared with resistance of control SCC samples. The behaviour of SCC-CCA subjected to sulphuric acid attack is consistent with that reported in Aimola, (2012) for normal concrete-CCA. The decrease in weight retained of SCC-CCA may be as a result of phosphoric oxide and potassium oxide present in CCA which may form potassium silicate and other silicates that may displace more calcium oxide and inhibit further formation of C-S-H gel. This may lead to the formation of micro voids in SCC-CCA and consequent reduction in weight retained (Mahmud et al, 2012).

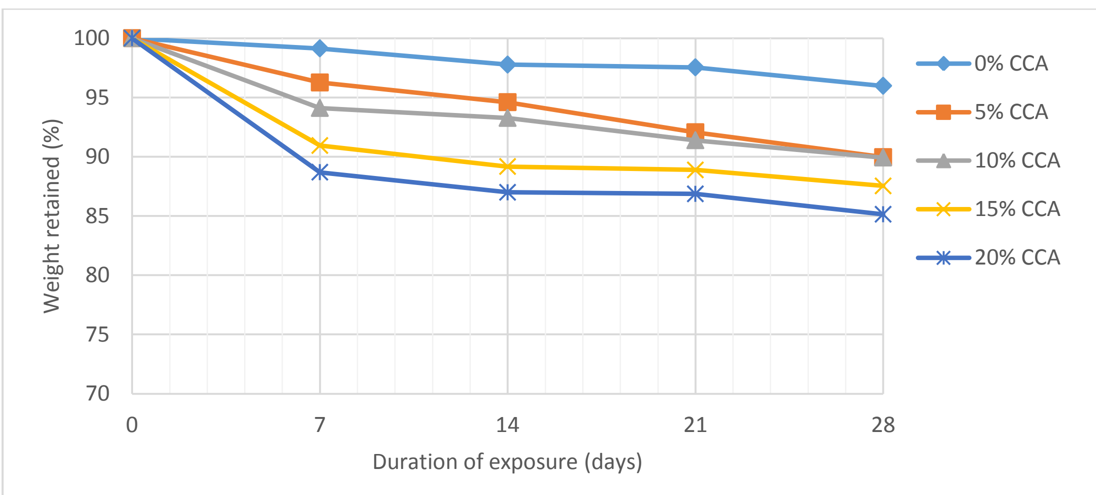

Figure 3: Resistance of SCC-CCA to sulphuric acid attack

Water Absorption of CCA-SCC

The water absorption of SCC-CCA increased with the increase in CCA content as shown in Figure 4. The increase in water absorption with increase in CCA content may be due to the increase in consistency in a mix containing CCA, in which water occupies the space in SCC and as it evaporates it leaves voids thus increase the absorption value (Kartini et al, 2010). Generally, the water absorption of SCC is lower than that for conventional concrete (Abdulhameed, 2005). The lower water absorption exhibited by SCC is an indication of lower porosity of SCC compared to the conventional concrete.

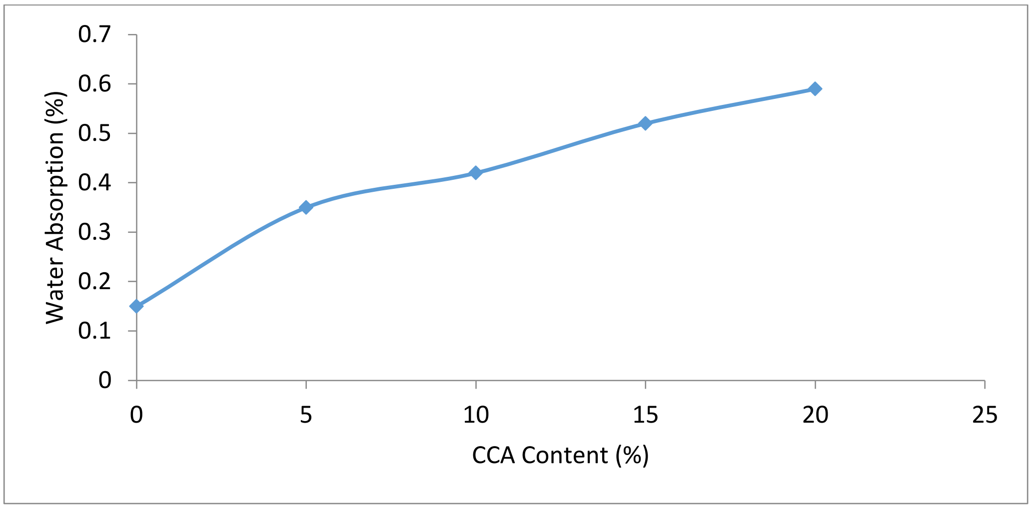

Figure 4: ***Water Absorption of SCC-CCA***

CONCLUSIONS

i) The CCA has a combined SiO_2, Al_2O_3 and Fe_2O_3 content of 71.32%, which can be classified as class F pozzolana.

ii) The compressive strength of SCC decreased with increase in CCA content. The 56 days compressive strength of the CCA-SCC ranged from 30.7 N/mm^2 to 52.1 N/mm^2, and up to 15 % CCA is recommended as partial substitute of cement for production of SCC.

iii) CCA decreased the resistance of SCC against sulphuric acid attack. The resistance of SCC-CCA

Decreased between 6.27 to 11.29 % compared with resistance of control SCC samples

iv) CCA increased the water absorption of SCC.

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