International Journal of Science, Environment
and Technology, Vol. 5, No 6, 2016, 4532 – 4544

ISSN 2278-3687 (O)
2277-663X (P)

VIABILITY OF USING CORNCOB ASH AS A POZZOLAN IN CONCRETE

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Abstract: Cement is the most utilised construction material, its global consumption only seconding that of water. Its demand has soared proportionately with the exponential rise in population to match required development. The heavily energy-intensive processes that are involved in its production contribute to about 7% (per cent) to 10% of the total global carbon dioxide (CO_2) emissions, with potentially adverse environmental implications and are economically expensive. These processes, and those of the production of concrete consume heavily on natural resources such as sand, gravel, water, coal and crushed rock, the mining of which mars the environment. It is however possible, that energy and cost efficiency can be achieved by reducing on the amount of clinker, and in its place utilizing pozolanic materials that require less process heating and emit fewer levels of CO_2. This study investigated the viability of corncob ash for use as a pozzolan in concrete. Tests were carried our by replacing cement by weight in concrete mixes with corncob ash at 5%, 7.5%, 10%, 15% and 20%steps at the point of need. The results were compared with a control specimen that was made with 100% cement (0% CCA). Durability was tested using the sulfate elongation test on specimens that were immersed in a 5% sodium sulfate (Na_2SO_4) solution. From the results, all replacements achieved impressive compressive strengths that were suitable for structural applications, while the sulfate elongation tests showed that CCA could be used in Na_2SO_4aggressive environments with an advantage. The findings also showed good repeatability and highlighted the potential of CCA to be used as an effective pozzolan in concrete.

Keywords: corncob ash, pozzolans, cementitious materials, maize cob ash, partial cement replacements.

INTRODUCTION

Apart from environmental friendliness, the use of cement replacements such as pulverised fuel ash (PFA), ground granulated blast furnace slag (GGBS), Silica fume (SF) and rice husk ash (RHA) has been associated with the reduction of the cost of concrete, improved workability and enhanced durability of hardened concrete, ultimately leading to enhanced service life of structures [1, 2]. This work investigated the viability of using corncob ash (CCA) as a pozzolan in concrete. Global warming is a phenomenon that brings about a rise in global temperatures due to the presence of excessive carbon dioxide (CO_2) in the atmosphere, and is cumulative and irreversible over timescales of centuries [3, 4]. The burning of fossil

*Received Nov 15, 2016 * Published Dec 2, 2016 * www.ijset.net*

fuels contributes to the greenhouse gas effect, which is a major cause of global warming [5]. Cement, a major constituent of concrete, is pivotal to development and is produced in virtually all countries [6]. One ton of concrete on average is produced every year for each human being in the world [7], a population that currently stands above 7 billion [8]. The growing population, matched by a corresponding increase in demand for socio-economic infrastructure that is aimed at creating affluent societies, especially in the developing world and former socialite countries, has led to a gradual increase in the demand for cement in the past few decades, with construction investment directly linked to higher GDP [9, 10]. Cement is deemed to have a considerably high carbon footprint, contributing immensely to global anthropogenic CO_2 [11]. It was described by Al-Salami and Salem [12] as the most utilised construction material in the world, its global consumption only seconding that of water. It constitutes between 7% (per cent) and 15% of the total mass of concrete [13], yet according to Sakai and Noguchi [10], the development of a nation is directly related to its consumption of concrete. The yearly global production of cement was 1.6 billion tons over 10 years ago, and accounted for about 7% of the total global CO_2 loading in the atmosphere, a considerably high level of emissions compared to 2% total global CO_2 emissions attributed to the aviation industry [14-16]. The production of a ton of cement emits approximately a corresponding ton of CO_2[17], making it the most energy-intensive material produced after steel and aluminium [11, 15]. In as much as development is required to match increasing populations, it should also be sustainable. The underlying principles of sustainability lie in the appropriate balance of economic, social and environmental impacts [18]. Steel et al. [19] defined sustainability as a road for society advancement in which progress must be in harmony with the natural world, rather than in conflict with it, while Gambhir [15], termed it as a regime in which the endeavors are towards meeting the needs of the present generation without compromising those of the future generations. With a heavy demand for concrete in the developing world and other major and equally populous economies such as China and India predicted, cement producing companies have not anticipated in the foreseeable future any major changes in production that will reduce on emissions [1]. However, energy efficiency can be achieved by reducing on the amount of clinker and utilizing pozolanic materials that require less process heating and emit fewer levels of CO_2[15]. Industrial and agricultural waste products such as PFA, SF, GGBS, RHA and CCA unnecessarily occupy space when stored or create environmental hazards when dumped in landfill. Their utilisation in the construction industry reduces the overall cost of construction, mitigates on the technical and environmental nuisance that is associated with production, decreases electric costs at power stations in the case of PFA, reduces solid waste, cuts on greenhouse gas emissions and conserves existing natural resources, thereby enhancing sustainability as well as improving the properties of fresh and hardened concrete [20, 21]. Corn is the main staple food in the Eastern and Southern Sahara Africa, accounting for more than 20% of domestic food production [22]. Corncob is the hard central core of corn, which bears the grain of the ear cob, while CCA is the remnant of incinerated corncob [1, 23]. Previous studies have dealt with blending CCA with cement at the factory and not at the point of need. Adesanya and Raheem [24], Olafusi and Olutoge [23] and Udoeyo and Abubakar [25] reported that CCA reduced the workability of concrete, yet it has been reported that one of the characteristics of pozzolans is to enhance the workability of mixes [1, 26, 27]. No work was found on the performance of CCA concrete in sulfate aggressive environments. This study involved replacing cement with CCA at the point of need, and investigated compressive strength, workability and sulfate attack.

METHODS

CCA was sourced from Kenya. Corncobs were incinerated under uncontrolled conditions in open air using charcoal fuel at about 650^0C (degrees Celsius) to 800^0C for over 8 hours until they turned to ashes. Snow retecement type CEM 1 52.5 N was used. The dimensions of cube and cylinder moulds were 100mm x 100mm x 100mm and 150mm in diameter and 300mm in height respectively conforming to BS EN 12390-1:2012 [28]. The target strength was class C32/40 at a mix ratio of 1:2:3. Cement was substituted with CCA by weight in steps of 0%, 5%, 7.5%, 10%, 15% and 20%.The 0% replacement was used as the control specimen to which all performances were referenced. A water cement ratio (WCR) of 0.47 was used for all mixes in a bid to achieve best strengths in line with Abram’s water cement ratio law, which states that the strength of a concrete mix is determined by the WCR, with lower WCR spelling higher strengths and vice-versa [29]. Aggregates and cement were weighed and mixed using a concrete mixer for a total of eight minutes, with a three-minute rest in-between the mixing [30]. Workability of the mixes was measured using the slump test method conforming to BS EN 12350-2:2009[31] while the casting of cubes and cylinders conformed to BS EN 12390-2:2009 [32]. To ensure repeatability, a total of three cubes were cast for each testing age and the average compressive strength was used [5, 33]. The specimens were left in the moulds for 24 hours, before being stripped, marked and submerged in a water tank at temperatures of 20^0 ±2 until they were tested. Compressive tests were performed to BS EN 12390-4:2000[34] guidelines at 7, 28, 56 and 91 days. The sulfate elongation tests conformed to ASTM C1012/C1012M[33]. Cubic prismatic samples measuring 160mm x 40mm x 40mm were prepared and cast. The lengths of test specimens were taken before they were immersed in a 5% Na_2SO_4 solution, which was maintained at a pH of 6 to 8and laboratory temperatures of $23^0C \pm 2^0C$. Length measurements were taken at 1, 2,3,4,8 weeks and 4, 8 and 9 months.

CHEMICAL ANALYSIS

Table 1 shows the oxide composition of CCA and cement that were used for this study, obtained by X-ray diffraction (XRD). Pozzolanic properties required by ASTM C618 [35] are referred to as **A*** and those of BS EN 197-1:2000[36] as **B***. CCA did not satisfy the pozzolanic recommendations of ASTM C618[35] and BS EN 197-1:2000[36] of the sum of SiO_2, Al_2O_3 and Fe_2O_3greater than or equal to (≥) 70% and neither did it satisfy the loss on ignition (LOI) requirements of BS EN 197-1:2000[36] or ASTM C618[35] of less than 5% and 10% respectively. However, BS EN 197-1:2000[36]'s requirement of anSiO_2 content of at least 25% in satisfied. The method that was used to incinerate CCA may have affected its chemical composition, since according to Bapat [1], incinerating RHA under controlled conditions can help to improve the oxide composition of the resultant RHA, a concept which could also be applied to CCA. For the requirements that were discussed by Tishmack, et al. [37] on sulfate attack resistance, CCA had relatively low levels of SiO_2 and high amounts of Fe_2O_3, which is an indication of low resistance to sulfate attack, even though CaO and the ratio of SO_3/Al_2O_3 were relatively low, a quality which, also according to Tishmack, et al. [37], contributes to higher sulfate resistance.

Table 1. Approximate oxide composition of OPC and CCA

Percentage (%) oxide composition	OPC	CCA	Pozzolanic properties requirements
Silicon (SiO_2)	21.9	38.8	**A*** and **B*** ≥70% or SiO_2> 25 for **B***
Aluminium (Al_2O_3)	4.0	7.9	
Iron (Fe_2O_3)	0.2	7.4	
Calcium (CaO)	66.5	1.8	
Magnesium (MgO)	1.4	2.1	
Sodium (Na_2O)	0.1	0.9	
Potassium (K_2O)	0.6	23.5	
Loss on Ignition (LOI)	-	10.8	**A*** ≤ 10 **B*** ≤ 5
Sulphite (SO_3)	2.5	0.59	**B*** ≤ 4
Blaine fineness (M^2/kg) (000)	3.2		

RESULTS AND DISCUSSIONS

Compressive strength

Table 1 and figure 1 show compressive strengths at 7, 28, 56 and 91 days of hardened concrete at 0%, 5%, 7.5%, 10%, 15% and 20% CCA replacements over a 91-day curing regime.

Table 2. Compressive strength of CCA replaced mixes (N/mm^2)

Curing age (days)	Compressive strength at various replacements (N/mm^2)					
	0%	5%	7.5%	10%	15%	20%
7	56.2	42.0	42.3	32.1	28.1	19.2
28	61.6	49.0	51.3	37.9	34.3	23.5
56	67.6	51.8	54.4	43.1	38.3	25.9
91	71.3	56.0	63.5	47.8	41.5	29.8

Apart from the 20% replacement, all other replacements realised compressive strengths that were above 25N/mm^{-2} at 28 days which, according to BS EN 197-7:2000[36] are suitable for use in structural concrete. At 91 days, replacements of up to 15% realized strengths that were above the target concrete strength class C32/40. An addition of CCA resulted in a decrease in compressive strength. Compressive strength increased with curing age in line with literature [1, 23, 24, 38, 39]. According to Bapat [1], and Adesanya and Raheem [24], the early age strength was solely as a result of the hydration of cement, with CCA only acting as an inert filler of voids, while the latter strength was due to the reaction of SiO_2 present in the CCA with free lime from cement hydration in a secondary reaction over time, to form strength giving compounds such as calcium silicate hydrate (C-S-H).

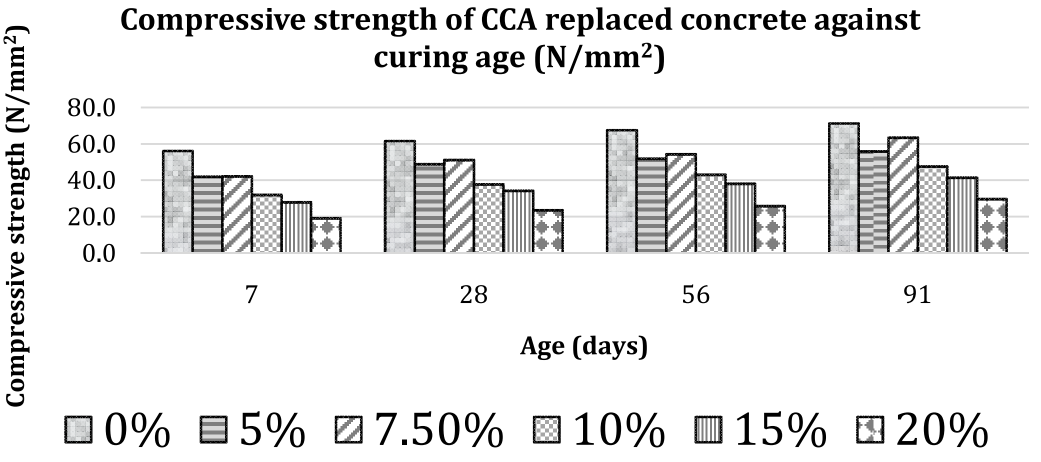

Figure 1. Compressive strength of CCA replaced concrete (N/mm^2)

Tensile strength

The tensile strength of CCA replaced concrete decreased with increased CCA replacement as shown in table 3 and figure 2. This was consistent with literature, which reported a decrease in the tensile strength of PFA specimens with increased PFA replacement Sarker [40].

Table 3. Tensile strength at percentage replacement (N/mm^2)

Percentage replacement	0%	5%	7.5%	10%	15%	20%
Tensile strength (N/mm^2)	3.6	3.5	2.3	2.8	2.4	2.1

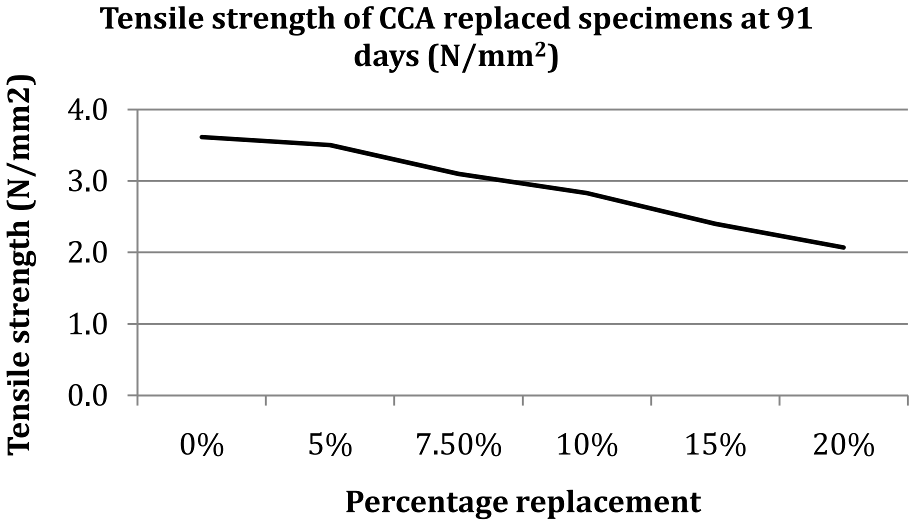

Figure 2. Tensile strength at percentage replacement (N/mm^2)

Density

Table 4 and figure 3 show the density of CCA replaced specimens at various curing ages. Consistent with literature that due to their lower particle specific gravities, SCMs provide an advantage by decreasing the mass of concrete per unit volume [1, 41], the densities of CCA replaced specimens were lower than those of 100% cement at all replacements, and decreased with further replacement. Densities were also observed to decrease with curing age, consistent with literature that finely divided particles of SCMs increase the density of concrete by micro filling the voids that are found in the transition zone of plain concrete in the early age, but decrease with further curing due to the consumption ofSiO_2 present in SCMs and free lime produced from the hydration of cement, through the secondary hydration over time to form strength giving compounds such as C-S-H [1, 24, 42].

Table 4. Density of CCA replaced concrete (Kg/m^3)

Curing age (days)	Density at percentage replacement (Kg/m^3)					
	0%	5%	7.50%	10%	15%	20%
7	2350	2354	2350	2310	2310	2300
28	2350	2350	2337	2301	2307	2270
56	2323	2334	2336	2288	2302	2245
91	2366	2333	2330	2286	2290	2235

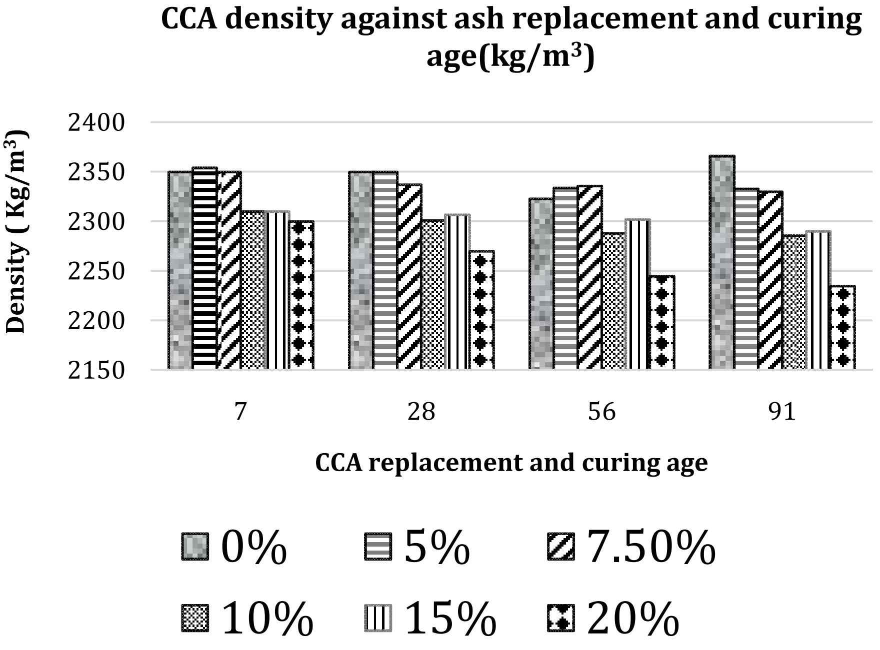

Figure 3. Density of CCA replaced concrete (Kg/m^3)

Workability

Table 5 and figure 4 show the slumps from the CCA replaced mixes at different replacement levels. Slumps were observed to increase with increased replacement. This was not consistent with the findings of Adesanya and Raheem [24], Olafusi and Olutoge [23] and Udoeyo and Abubakar [25], all of who reported a decrease in workability with an increase in CCA replacement, and explained it as being a result of a higher water demand that is caused by the high amount of silica in CCA. These results indicate that in line with Abram's law of WCR, CCA can be used with an advantage of reducing the water content and consequently improving compressive strengths [29].

Table 5. Workability of CCA replaced concrete (mm)

Percentage replacement	0%	5%	7.5%	10%	15%	20%
Slump (mm)	0	10	20	40	100	250

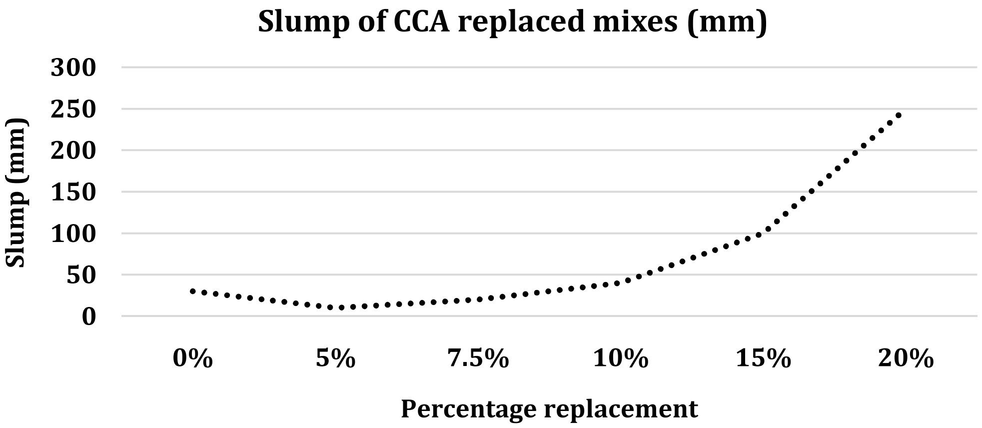

Figure 4. Workability of CCA replaced mixes (mm)

Sulfate resistance

Table 6 and figure 5 show the Percentage elongation of CCA replaced specimens in a Na_2SO_4 solution. The CCA specimens showed lower expansions than the control specimens, signifying the reduction of gypsum and ettringite through the introduction of SiO_2 present in CCA, which, through the secondary hydration consumes the calcium hydroxide [$Ca(OH)_2$] that is produced during the hydration of cement in the early age, to form C-S-H [12, 43-45]. According to Al-Salami and Salem [12], Alasali and Malhotra [43], Al-Amoudi, et al. [44] and Moon, et al. [45], the increased C-S-H content that results from pozzolanic reactions, consuming and reducing the amount of $Ca(OH)_2$ and aluminate hydrate ($CaAl_2O_4$), and the filler effect of unreacted pozzolans can explain the ability of SCM concretes to resist Na_2SO_4 attack. The sulfate resistance observed on CCA specimens could also be attributed to the low levels of CaO and the low ratio of SO_3/Al_2O_3, which according to Tishmack, et al. [37], contribute to higher sulfate resistance. This better performance in the Na_2SO_4 solution signifies that CCA could be used with an advantage in Na_2SO_4 environments.

Table 6. Percentage elongation of CCA replaced specimens in a Na_2SO_4 solution

Specimens	Percentage elongation in Na_2SO_4 over time							
	Week 1	Week 2	Week 3	Week 4	Week 8	4 months	8 months	9 months
Control	0.000	0.003	0.012	0.016	0.037	0.053	0.075	0.094
7.5% CCA	0.000	0.003	0.003	0.013	0.025	0.028	0.062	0.088

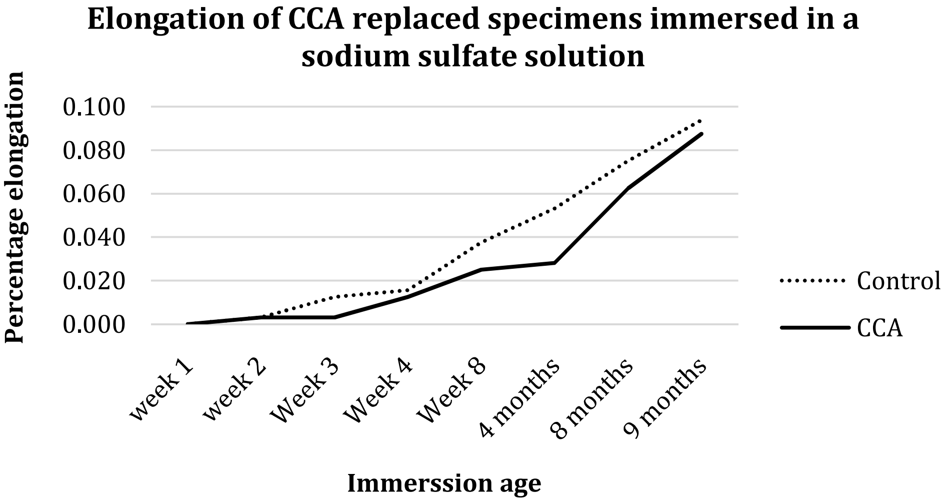

Figure 5. Percentage elongation of CCA replaced specimens in a Na_2SO_4 solution

Conclusion

This study investigated the viability of using corncob ash as a pozzolan in concrete. Although the CCA used did not satisfy the minimum chemical composition requirements for pozzolanic materials of $SiO_2+Al_2O_3+F_2O_3 \geq 70\%$, it satisfied the requirements of a SiO_2 content of not less than 25%. The chemical composition of CCA can however be improved by incinerating corncobs under controlled conditions. The compressive and sulfate resistance tests showed good repeatability, with strengths capable of structural applications being observed over all replacements. These results indicate that CCA could be used as a pozzolanto mitigate on the cost of cement and its negative impacts on the environment, and could also be used with an advantage in Na_2SO_4 aggressive environments.

Acknowledgement

The authors would like to acknowledgement Kevin Smith, the Materials Laboratory Manager at the Leeds Beckett University for his help, Agnes Mwangi and Samwel Kibiribiri for patiently processing and supplying us with corncob ash, and Rebecca, Tamiaand Philomena Chege for their support.

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