Durability Performance of Cow-Bone Ash (CBA) Blended Cement Concrete in Aggressive Environment

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Abstract-This study assessed the durability of cowbones-ash blended cement concrete in aggressive environment. The experimentations covered the; production of cowbone ash (CBA) from waste cowbones, physical and chemical characterisation of the cowbone ash and the production of cowbone ash blended cement concrete (CBABC) mixes containing; 0%, 10%, 20% and 30% CBA as partial replacement of cement. Uniform water to binder ratio of 0.50 along with concrete mix ratio 1:2:4 was adopted. The CBABC cubic specimen of sizes 100mm by 100mm by 100mm were exposed to aggressive and non-aggressive conditions. The specimens were tested for compressive strength after 28 days curing duration.

The oxide composition revealed that the CBA is rich in Calcium oxide content with a value of 63.86% by weight. The CBABC mixes displayed enhanced workability as the proportion of CBA increases. For the non aggressive curing condition, the CBABC concrete containing 0%, 10%, 20% and 30% CBA content exhibited average compressive strength of, 23.92 N/mm^2, 25.18 N/mm^2, 21.36 N/mm^2 and 20.86, N/mm^2 .

The compressive strength of both the conventional concrete (containing 0% CBA content) and CBABC concrete specimens reduces with exposure to aggressive condition. Comparatively in terms of compressive strength, the CBABC mix containing 10% CBA content displayed higher resistance to aggressive condition than all other mixes containing; 0%, 20%, and 30%, CBA content. At 28days of exposure to HCl (aggressive curing condition) CBABC containing 10% CBA exhibited 21.56 N/mm^2 (representing 86% of its original strength when cured in water), and it displayed 13.97 N/mm^2 (being 55% of its original strength) upon exposure to H_2SO_4. Thus, Cowbone ash blended cement containing 10% replacement of CBA content has the optimum potential for application in aggressive environment and especially in hydrochloric acid prone environment. The findings of this study indicate the potential applicability of the innovative 10% CBABC as a durable alternative to the conventional Grade C25 concrete mixes in hydrochloric (HCl) acid prone environment.

Index Terms- Cowbones ash, Concrete, Compressive strength, Durability, aggressive environment, hydrochloric acid (HCl), Sulphuric Acid (H_2SO4).

I. INTRODUCTION

In the creation of the built environment, a concrete structure is expected to maintain its design strength and serviceability requirement throughout its design life. However, the ability of concrete structures to fulfil this requirement often gets aborted by their application in aggressive environment and consequent chemical/acid attack. Concrete containing ordinary Portland cement are susceptible to deterioration when exposed to acid attack due to the high alkalinity of the Portland cement.

At pH value below 6.5, acidic substances including, carbonic acid, sulphuric acid , hydrochloric acid e.t.c causes deterioration and decomposition of concrete with increase severity as the pH value lowered down to 4.5. The product of hydration of cement 'calcium hydroxide' ($Ca(OH)_2$) is the active compound which is mostly affected during acid attack [1]. $Ca(OH)_2$ is highly soluble and it leaches out of the concrete when exposed to acidic solution, thereby creating room for rapid penetration of the acidic solution into the pores of the concrete [2].

To increase the resistance of concrete in aggressive environment, literatures [3];[1] had recommended the use of pozzolan blended cement or blastfurnace slag blended cement (amongst other remedies) as a way of reducing the quantity of $Ca(OH)_2$ in the hydrated cement paste. Recently the use of cow bone ash (CBA) as supplementary cementitious material in concrete production had been reported. For example, [4] and [5] have previously reported that the compressive strength of concrete increases appreciably at 10% optimum percentage replacement of cement with CBA.

Therefore, considering the expected reduction in quantity of $Ca(OH)_2$ that partial replacement of cement with CBA is expected to cause couple with the fact that CBA usually contains high content of calcium oxide (CaO) in its oxide composition, this study investigated the durability performance of CBA blended cement concrete in aggressive condition. It is expected that the outcome of this study may provide information on the applicability or otherwise of CBA blended cement in aggressive environment.

II. MATERIALS AND METHODS

A. Materials

The materials used for the production of concrete in this research were, cement, sand, granite, Cow bone ash (CBA), water and acidic curing media.

1) Cement: The cement used was ordinary Portland cement (grade 43) free of lumps which met all the requirements of [6].

2) Cow-bone Ash: The Cow bones ash (CBA) used in this study was systematically produced from locally obtained cow bones. The procedure adopted for preparation of the CBA includes; washing of cow bones to remove dirt, drying of waste cow bones to surface dried condition and heating of the dried cow bones in muffle furnace at temperature of 915^{o}C (being the reactivity temperature range) and grinding of the heated cow bones to powdery ash. The resulting CBA was sieved through BS sieve No 200 and the oxide composition of same was determined using X-Ray Fluorescence, XRF test. Particle size distribution, bulk density and specific gravity of the CBA were also determined in accordance with [7] and [8] respectively.

3) Fine aggregate and Coarse Aggregate: Locally available sand which conformed to the requirement for concrete production was used as fine aggregate in this research. Crushed granite of 20mm particle size which satisfied the requirement of [9] for concrete production was used as the coarse aggregate in this research.

4) Water and Acidic Curing Media: The water used for mixing the constituent material of the concrete was distilled water which conformed to the requirement set out by [10]. The same type of water was employed for the curing of the concrete cubes in normal curing condition and for preparation of the acidic media. Hydrochloric acid (HCl) solution and Sulphuric acid (H_2SO_4) solution were used for simulating the aggressive curing condition for assessing the durability of the CBA blended cement concrete produced in this study. Concentrated acidic solutions of the HCL and the H_2SO_4 were separately prepared to pH values of 1.09 each. 5% concentration of HCl and H_2SO_4 acid solutions corresponding to pH value 1.09 were obtained by dissolving 1250 ml of the respective acids in 23.75 litres of distilled water

B. Experimental Procedures

1) Mix Proportioning and Preparation of concrete specimens: A nominal concrete mix ratio of 1:2:4 cement, fine aggregate and coarse aggregate along with water cement ratio of 0.5 was adopted for this study. The constituent materials were batched by weight for measurement accuracy. CBA was used to partially replace cement in the concrete produced. The levels of percentage replacement of cement with CBA were at; 0%, 10%, 20%, and 30%. The concrete mixes produced were designated as; Portland cement concrete (PCC) for 0% replacement of cement with CBA and Cowbone ash blended cement concrete (CBABC) covering subcategories; CBABC1, CBABC2, and CBABC3 mixes corresponding to 10%, 20%, and 30% replacement of cement with CBA respectively. The detail of the mix proportioning of materials for the concrete mixes is presented in Table 1. The concrete cubes samples were cured for 28days in three different curing media including; distill water (simulating exposure to normal/non aggressive condition), Hdrochloric acid (HCl) solution of 5% concentration and sulphuric acid (H_2SO_4) solution of 5% concentration (both acidic curing media simulating exposure to aggressive condition). For each curing media/exposure conditions investigated, three (3) concrete cubes samples were produced and tested, the average values of the results was computed and reported.

TABLE 1
MIX PROPORTIONING OF MATERIALS FOR PRODUCTION OF CONCRETE MIXES

Concrete Designation	CBA Content (%)	Mass of Constituents in (kg)			
		Cement	CBA	Fine Agg.	Coarse Agg.
PCC	0	18.60	0.00	37.20	74.40
CBABC1	10	16.74	1.86	37.20	74.40
CBABC2	20	14.88	3.72	37.20	74.40
CBABC3	30	13.02	5.58	37.20	74.40

*Note: Agg. represents aggregate

2) Slump Test: The slump test is a measure of the consistency of fresh concrete and a means of identifying discrepancies in the uniformity of concrete mixes fluidity. The slump test was thus carried out in accordance with the [11] to determine the effect of CBA blended cement on the workability of the concrete mixes.

3) Compressive Strength Test: Compressive strength is the capacity of a material or structure to withstand loads tending to reduce its size. Compressive strength of concrete is one of the major properties that are affected when the hydration product of Portland cement is attacked by the acidic substances present in aggressive environment [12]. Thus, compressive strength test was carried out on each of the; PCC, CBABC1, CBABC2 and CBABC3 concrete specimens cured in each of the three curing media. Three cubes were tested at the age of 28 days for each of the mixes. The compressive strength test was carried out on hardened cured concrete cubes. The test was conducted in accordance with procedures recommended by [13]. The effect of exposure to the different acidic solutions at 5% concentration on the compressive strength of the CBABC was assessed by comparing the compressive strength of the concrete in water curing medium with those of the acidic curing medium.

III. RESULTS AND DISCUSSION

The results obtained from the; chemical characterisation of material, slump test and the compressive strength tests are discussed in this section.

A. Chemical and Physical Properties of CBA

The cementitious characteristic of a calcined ash is usually indicated by its oxide composition. The chemical analysis of CBA (Table 2) shows that the total percentage composition of Iron oxide (Fe_2O_3 = 0.025%), aluminium oxide (Al2O3 = 13.21%) and silicon dioxide (SiO2 = 19.02%) was found to be 32.26%. This is less than 70% minimum requirement recommended by [14] required for a cementitous material to be regarded as pozzolana. Thus, oxide composition of CBA used in this study does not satisfy the requirement for pozzolanic materials, it can however be regarded as a cementitious filler/additive considering its high CaO content which was found to be 63.86% by weight. The specific gravity and bulk density of CBA were found to be 1.29 and 1.13g/cm^3 respectively. The specific gravity exhibited by the CBA is less than the known specific gravity of cement which is 3.15 [1], thus CBA can be regarded as a lightweight and voluminous material. The practice of batching CBA by weight rather than by volume is recommended during usage as supplementary cementitious material because more of its volume will be needed to replace equal weight of cement in concrete.

TABLE II
CHEMICAL AND PHYSICAL CHARACTERISTICS OF THE CBA

Chemical Properties of CBA	
Elemental Oxides	% Weight
SiO_2	19.02
Al_2O_3	13.21
CaO	63.86
Fe_2O_3	0.025
Na_2O	0.86
MgO	1.01
K_2O	0.05
Cuo	0.015
Fe	0.016
LOI	0.90%
Physical Properties of CBA	
Specific Gravity	1.29
Bulk Density	1.13g/cm^3
Particle size range	75µm- 1.18mm

B. Slump Values of Cowbones Ash Blended Cement Concrete

Table 3 shows the results of the slump test carried out on the fresh concrete with varying percentage of CBA. The results shows that the slump value of the concrete mixes increases with increasing CBA content, the PCC mix which contained 0% CBA content displayed 30mm slump value while the CBABC mixes containing 10, 20 and 30% CBA content displayed 33mm, 37mm and 40mm slump value respectively. Slump value of a freshly mixed concrete is an indication of its flow and overall workability. Thus, the increasing slump value with increasing CBA content implies that the mixes became wetter and more workable as the CBA content increases. This may be attributed to the higher fineness and low specific gravity of CBA compared to the specific gravity of cement. This result is similar to findings of previous study [15] in which workability of concrete was found to increase steadily with incremental addition of CBA. For all the mixes prepared in this study, the slump values range from 30mm to 40mm which can be classified as slump S1 in line with [16].

TABLE III
SLUMP TEST RESULT OF CBA BLENDED CEMENT CONCRETE

Concrete Designation	CBA content (%)	Water/binder ratio	Slump (mm)
PCC	0	0.5	30
CBABC1	10	0.5	33
CBABC2	20	0.5	37
CBABC3	30	0.5	40

B. Compressive Strength of Concrete Specimen in Aggressive and Non Aggressive Cuing Media

The summary of the 28 days average compressive strength displayed by each of the mixes in aggressive and non aggressive condition is presented in Table 4.

TABLE IV
COMPRESSIVE STRENGTH OF CBA BLENDED CEMENT CONCRETE IN AGGRESSIVE AND NON-AGGRESSIVE CONDITION

Concrete Designation	CBA Content (%)	Average Compressive strength (N/mm^2) @ 28 days		
		Normal Curing Condition	Acidic/aggressive Curing Condition	
		H_2O (Distil)	HCL Solution	H_2SO_4 Solution
PCC	0	23.92	17.43	10.81
CBABC1	10	25.18	21.56	13.97
CBABC2	20	21.36	16.04	10.75
CBABC3	30	20.38	14.12	8.23

1) *Compressive Strength of Concrete Specimen Cured in Water*: The average compressive strength for each replacement level of cement with CBA at 0%, 10%, 20%, and 30%, for 28 days curing age is presented in Table 4. The compressive strength improves as the CBA content increased from 0% to 10% and thereafter the strength reduced gradually until the CBA content reaches 30%. In all the mixes produced, 10% CBA replacement level appears to be the optimum replacement level of CBA in concrete, as CBABC1 mix displayed 5%, 17% and 21% higher average compressive strength compared to the PCC, CBABC2 and CBABC3 mixes respectively. The average compressive strength exhibited by the CBABC1 satisfies the 25N/mm^2 standard cube compressive strength recommend by British standard for Grade C25/C30 concrete at 28 days curing age. Also, this result is in line with those reported by previous study [4];[5] regarding the optimum percentage replacement of CBA in concrete. This means that at 10% CBA content, CBA blended cement concrete is capable of exhibiting higher compressive strength compared to conventional Grade C25 concrete. Also, the average compressive strength of 20 N/mm^2 obtained at 30% replacement level shows that CBA can be used effectively up to 30% replacement level in cement for production of lightweight concrete. This may be attributed to the high CaO content of the CBA which may have caused a slight strength increase through reduction of the total pore volume as some of the liquid water are converted to solid form [2].

2) *Compresssive Strength of Concrete Specimen Cured in Acidic Media:* The results of compressive strength of concrete specimen produced with cement partially replaced with CBA and immersed in acidic curing media, (namely; hydrochloric (HCL) and sulphuric acid (H_2SO_4) solutions of 5% concentrations is presented in Table 4. Among the two acidic solutions used in evaluating the durability of Cowbones ash blended cement concrete; HCl caused the least deterioration to the concrete strength for all mixes while utmost damage/deterioration was caused by H_2SO_4. However, the concrete mix which contained 10% CBA content (CBABC1) displayed the highest resistance to the deteriorating effect of both acidic solutions. After 28 days exposure to respective HCL and H_2SO_4 solutions, CBABC1 displayed 21.56 N/mm^2 and 13.97 N/mm^2 which represents 86% and 55% of its original strength when cured in water media. At 28days of curing in HCL, all other mixes including the; PCC, CBABC2 and CBABC3 displayed 73%, 75% and 68% of their original strength respectively. Also, at 28days of curing in H_2SO_4, the PCC, CBAC2 and CBABC3 respectively displayed 45%, 50% and 39% of their original individual strengths. Thus, 10% replacement level of cement with CBA appears to be the optimum replacement requirement for better durability

characteristics in CBA blended cement concrete. Durability improvement of CBA appears to be more effective in resisting HCL acid attack rather than H_2SO_4 acid attack. Amongst other possible reasons, the enhanced resistance of CBABC to HCL attack may be attributed to the weak acidity of HCL compared to the H_2SO_4.

IV. Conclusion

The compressive strength of concrete produced with cement partially replaced with CBA in different acidic media of Hydrochloric acid of sulphuric acid solutions has been studied. Concrete made from cement blended with Cowbone ash (CBA) displayed reduced compressive strength when immersed in hydrochloric and sulphuric acid solution. Comparatively, apart from displaying the highest average compressive strength among all the mixes tested in normal curing condition, the CBA blended cement concrete containing 10% CBA content displayed the highest resistance to deteriorating effect of the acidic solution retaining 86% of its original compressive strength. The resistance of the 10% CBA content CBABC concrete was higher in Hydrochloric acid compared to the Sulphuric acid. It can therefore be deduced that CBA blended cement containing 10% CBA is effective in mitigating the effect of chemical attack by HCL on concrete.

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