The Impact of Guinea Corn Husk Ash as an Admixture for Crack Control in Concrete

Peter I. Aburime, Emmanuel E. Ndububa and David O. Kpue

***Abstract* — Guinea corn husk, a post-harvest agricultural waste common in Northern Nigeria is often heaped up constituting environmental nuisance. Guinea Corn Husk Ash (GCHA) is an incinerated by-product of it. In this experimental investigation, it was used to replace cement in concrete at levels of 0%, 5%, 10%, 20%, 30% and 40% by weight. The sample cubes were casted and cured for 3, 14, 28 and 56 days before crushing. Before then, the chemical constituents of the GCHA were determined from an X-Ray diffraction analyzer. The oxides found in the ash included SiO_2 (85.4%), K_2O (4.01%), Fe_2O_3 (0.64%), CaO (2.04%) and NaO_2 (0.98%). SO_3 and AI_2O_3 were not detected. The combined percent of SiO_2, Al_2O_3 and Fe_2O_3 of 86.04% is above the 70% benchmark for a pozzolana material. Also, SO_3 and NaO_2 fell below the maximum allowable values of 4% and 1.5% respectively. The fresh concrete had slump values that ranged from 11mm for 0% cement replacement to 3.6mm for 40% replacement. The hard concrete had the highest compressive strength value of 23.67 N/mm^2 for plain concrete and 49.3 N/mm^2 at 5% GCHA replacement level. All were at 56 days of curing, satisfying quality for heavy load bearing. Beam samples cured for 3, 14, 28 and 56 days were subjected to flexural tests until they developed cracks. The cracks were measured for lengths (CR_L) and width (CR_W) for different replacement levels and curing days with a crack measuring microscope. The results show that, at 14days curing, there is a trend in the crack values' reduction for the hardened GCHA concrete. This trend is also marginally seen for the 28 day cured samples, particularly at up to 20% replacement levels. The decrease in crack values were up to 17.2% and 2091% for CR_L and CR_W respectively. However, there were no significant crack controls with samples of higher replacement levels and those cured for 3 and 56 days. GCHA concrete can therefore be used to for heavy load bearing structures and for crack control at 5 – 20% replacement levels when cured for 14 days and 38 days.**

***Index Terms* — Concrete, Crack Measurements, Guinea Corn Husk Ash, Pozzolana.**

I. Introduction

Guinea Corn (GC) just like every other cereal commonly cultivated in Northern Nigeria is a staple food. The corn husk, a product of post-harvest agricultural activity is often heaped up and largely constituting environmental nuisance, though may be fed to livestock [1]. This is a global problem. The ash derived from incinerating the GC is no exception. Past research efforts show that the ashes of many agro-waste materials can be used to produce concrete and mortar through partial replacement of the Ordinary Portland Cement (OPC). Cement replacement of 5-25% levels showed various improvements and decline in the physical properties of concrete [1]. The seeds of G C as shown in Fig. 1 are small and round. They present in different colors of yellow, white, brown and red depending on species. As a staple food, it contains food minerals as Calcium, Manganese, Iron and Selenium [2].

Fig. 1. Harvested bunch of Guinea Corn showing the seeds and husks.

It was reported that at 5% level of GCHA, there was a marked increase in the compressive strength and density values while with further increased levels the reverse was the case, [1]. When produced under controlled burning temperature GCHA has been found to be very rich with a good percentage of Silica content which attest to its pozzolanic property. A Pozzolan is defined as a siliceous material which possesses little or no cementing properties but when in a finely graded form in the presence of moisture will chemically react with Calcium Hydroxide (CaOH) at ordinary temperature to form compounds possessing these cementing properties [3]. This CaOH is liberated during the hydration of OPC. Pozzolanas combine with the free CaOH liberated during the hydration of OPC to produce insoluble calcium silicates that help to reduce mortar and concrete attacks from sulphates, salts and chlorides [4].
The free CaOH are as given in the hydration equations of cement [5] and shown Eq. (1) and (2):

$$C_3S + 6H \rightarrow C_3S_2H_3 + 3Ca(OH)_2 \quad (1)$$

$$2C_2S + 4H \rightarrow C_3S_2H_3 + Ca(OH)_2 \quad (2)$$

where C_3S and C_2S are the Tri-calcium silicate and Di-calcium silicate compounds in cement. $Ca(OH)_2$ is the free CaOH or lime.

Published on October 7, 2020.
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Other forms of ash from burnt agro-wastes in the study area include Locust Bean Husk Ash, Rice Husk Ash, Millet Husk Ash and Corn Cob Husk Ash. When impregnated with lime and used to stabilize laterite, GCHA improved the compressive strength of the laterite up to an optimum percent proportion of 10% [6]. A report on Fonio Husk Ash (FHA) showed that the optimum percent for improved compressive strength was at 5% replacement. This was in addition to improved consistency and setting times [7].

Rice Husk Ash (RHA) is probably the most researched among the ashes from agro-wastes. Reports on RHA and others [8] show that optimum replacement level are within the 5% bracket for improved compressive strength, and split tensile test as in the case of RHA [9]. When RHA was prepared from charcoal powered incinerator, it recorded lower strength and durability properties in comparison with plain concrete, even though the values obtained were good enough for structural use [10]. However, there was an improvement in the compressive strength when the RHA samples were ground to Nano-size and replaced at 10% in porous concrete [11].

In this report, the replacement levels adopted were 0%, 5% 10%, 20%, 30% and 40% of GCHA over OPC by weight, then cubes and beams casted were cured for 3, 14, 28 and 56 days respectively.

Concrete structures are bound to undergo deterioration due to age and the presence of various elements in the environment. The presence of cracks is an indication of high voids within the concrete. Cracks lead to the reduction in engineering properties, like compressive, tensile and shear strengths respectively. Cracks in concrete structure result from the development of strains and stress within the concrete [3]. These combined factors may eventually lead to the structural failure. The failure may be minimized or avoided through an investigation of the use of GCHA as an additive for crack control in the concrete production. Could GCHA be that crack controlling constituent material in the concrete composite which in combination with low-heat hydration cement may further reduce the internal adiabatic temperature rise during concreting, that subsequently reduce concrete cracking? This is the object of this investigation. Fineness of cement affects the rate of hydration and hence increase in strength. The finer the cement, the faster it reacts with water and strength development increases and correspondingly high heat of hydration.

Additive used in concrete is defined as finely divided inorganic material that may be added to concrete in order to improve or achieve special properties. It is an important means of changing the concrete properties. The deformation property and anti-cracking ability of concrete can effectively be improved by the adoption of additives with a good anti-cracking ability [3]. It is important to understand that all cracks may result from various causes and its effects on the life of the structure emanates from the methods and analysis of design, loading, and climatic condition which are relevant to the structure, [4]. The propagation of cracks should not be such as to be detrimental to its life span in relation to its usage. If such defects are noticed it can be addressed appropriately so that the life of the structure is not compromised and will not ultimately result in the reduction of strength capacity and structural stiffness. It is worthy to note that from laboratory studies there appears to be a significant increase in crack width due to corrosion. This in turn reveals that smaller cracks (<1mm) had little or no effect on process of corrosion, while larger cracks (>1mm) increases rate of corrosion [12]. Recent studies on reinforced concrete beam have shown that under sustained loading which tends to open up cracks, in turn can produce high rate of corrosion leading to loss of strength [13].

II. Materials and Methods

A. *Materials and their Preparations*

The materials used for this report includes, OPC, fine and coarse aggregates (river sand and quarry coarse aggregates), water and GCHA. The OPC was obtained from the "Dangote" brand of Obajana plant in Kogi State, Nigeria. The aggregates, (Fine and Coarse) were obtained from the Kuje Area of Abuja, Nigeria. The GCH which is a post-harvest material by the local farmers after the seeds have been extracted was obtained from Tukuba village in Kuje Area. The aggregates were then washed to remove silty and other deleterious materials and subsequently dried under sunlight. The fine aggregates were sieved to pass through 200 mm and 63μm sieve sizes, [14].

The GCH was burnt up to a regulated temperature of 600ºC in an incinerator at Sheda Science and Technology Complex (SHESTCO) in Abuja and allowed to cool before grinding to fine powder.

B. *Chemical Analysis of GCHA*

The chemical analysis on the material was carried out at the Material Science Laboratory of SHESTCO to determine its chemical composition and suitability as a pozzolana in accordance with European Standards [15]. The X-Ray diffraction method of analysis was used. The Bogue composition equation was also used to compute the composition of Tri-calcium Silicate (C_3S) and the Di-calcium Silicate (C_2S) in the ash. The composition equation is given as [5]:

$$C_3S \rightarrow 4.07CaO - 7.60SiO_2 - 6.72Al_2O_3 - 1.43Fe_2O_3 - 2.85SO_3 \quad (3)$$

$$C_2S \rightarrow 2.87SiO_2 - 0.75C_3 \quad (4)$$

C. *Sieve Analysis and Fineness*

Sample fractions of OPC and GCHA were measured and passed through a mechanically operated sieve of size 150μm. In accordance with the relevant standard [16], the % sample retained *R* was a measure of the Fineness, i.e.:

$$Fineness\ (R) = \frac{Weight\ of\ sample\ retained\ on\ 150\mu m}{Weight\ of\ sample} x100\% \quad (5)$$

D. *Workability*

Slump tests were carried out on each of the mix proportions in accordance with the relevant British standards [17].

E. Compressive Strength Tests and Density

The compressive strength is derived from cube crushing. Cubes were casted from the samples into mold of sizes 150x150x150 mm as shown in Fig. 2 and casted for each replacement levels of 0%, 5%,10%, 20%, 30% and 40%. They were cured for 3, 14, 28 and 56 days respectively, then crushed in a universal testing machine (UTM) with capacity for 1000KN at crushing rate of 6KN/s (see appendix 1). To obtain the average compressive strength, three cubes were then casted for each replacement level mixes to obtain the average values [18].

Fig. 2. Compression of cube sample.

F. Density Test

The first was the test on fresh concrete that was conducted in accordance with British standard [19] and the other carried out on hardened concrete [20]. In the later, the cube samples were removed from the curing tank and water allowed to drain for 30 minutes, the cubes were then weighed.

The average values of three samples were used and calculated from the following equation:

$$Density = \frac{Mass\ of\ concrete}{Volumn\ of\ sample} \tag{6}$$

G. Flexural Tests and Crack Measurement

The Crack measurement (length and width) was carried out in accordance with [21] in conjunction with flexural strength test using mold sizes 450 x 150 x 150 mm as shown in Fig. 3 in accordance with British standards [22]. Beams were casted for each replacement levels of 0%, 5%,10%, 20%, 30% and 40% and cured for 3, 14, 28 and 56 days respectively.

Fig. 3. Measuring the sample beams.

To obtain the average MOR, three beams were then casted for each replacement levels and was subsequently tested to obtain the average value. The adoption of the centre-point enabled the MOR to be computed from the expression:

$$MOR = 3PL/2b\,d^2 \tag{7}$$

where, P is the maximum total load on the beam, L is the span, b and d are the width and depth of beam respectively.

At the end of each curing period, the beams were removed from the curing tank, allowed the water to drain, weighed (see appendix 2) and crushed in a universal testing machine as shown in Fig. 4.

Fig. 4. Crushing of beam showing the first crack.

Thereafter, the crack width and length were measured for each of the plain and GCHA concrete beams. The values were read with a hand held crack measuring microscope (ELE, UTC-4050) and done to an approximate value of 0.02mm accuracy, as shown in Fig. 5 and the appendix 3.

Fig. 5. Crack measurement with microscope.

III. RESULTS AND DISCUSSIONS

A. Chemical Analysis of GCHA

Shown in Table 1 and Fig. 6 are the results of the chemical analysis with the % proportions of the oxide content.

TABLE 1: RESULT OF CHEMICAL ANALYSIS OF GCHA AND OPC

Oxide Content	Al_2O_3	SiO_2	SO_3	Na_2O	K_2O	CaO	MgO	TiO_2
% GCHA	0	85.4	0	0.98	4	2.04	0.01	0.08
% OPC	4.84	53.9	2	0	0	34.4	0.03	0.2
Oxide Content	SC_2O_3	MnO	Fe_2O_3	CuO	Z_nO	SrO	ZrO_2	L.O.I
% GCHA	0	0.098	0.64	0.036	0.075	0.019	0.013	6.4
% OPC	0.56	0.01	1.29	0.02	0	0.84	0.02	2.24

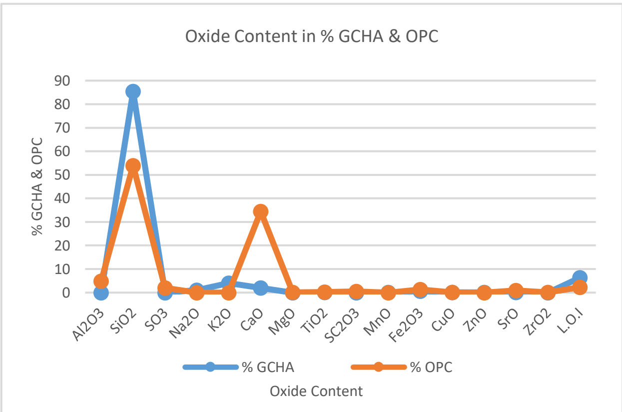

Fig. 6. Oxide Content Vs % GCHA & OPC.

The total combined content of silica (SiO_2), alumina (Al_2O_3) and ferric oxide (Fe_2O_3) was 86.04% which is above the specified 70% for pozzolanas [3]. This proves the suitability of GCHA as a pozzolana and confirms an earlier result [3]. Sulphur trioxide (SO_3) content is zero, falling below the maximum specified content of 4%. An excess of SO_3 could lead to expansion and subsequent disruption of the set cement paste thereby contributing to cracking of cement. The sodium oxide content of 0.98% is below the maximum prescribed value of 1.5%. Higher quantities can substantially react with some aggregates causing concrete disintegration and also adversely affect the rate of the gain of strength of cement [5]. This also reduces crack risks in concrete. The Loss on ignition content of 6.4% is well below the prescribed maximum of 10%. The ash was therefore eminently qualified as a possible crack reducing and suitable pozzolana for concreting. Calculated results from equations (3) and (4) gave C_3S and C_2S values of -641.64 and 726.33 respectively. The typical OPC values are 54.1 and 16.6 respectively. The insignificant value of C_3S in GCHA only attest to the very low CaO content. This confirms the very low CaOH (lime) content in GCHA and indeed pozzolanas generally which rather use the lime produced from the equations shown in (1) and (2) to produce binding properties. The very high C_2S value show that GCHA has very high SiO_2 content. Since C_2S is controlled by its slow intrinsic slow rate of reaction, then it's very high content in GCHA will contribute to slower setting times when compared with 0% GCHA paste.

B. *Sieve Analysis and Fineness*

The results of sieve analysis of GCHA and OPC are shown in Table 2 and Fig. 7. Comparing the similarity of the particle size distribution curves, it is evident that GCHA may be considered a filler material in addition to its pozzolanic properties. The results revealed that the percentage of GCHA and OPC retained on sieve no. 75µm was less than 22 % respectively (15.8% and 18.9%). This attest that both are good for casting concrete elements. The fineness values *R* of 11.2 (GCHA) and 8.8 (OPC) show the closeness of both in Fineness and that GCHA could easily replace the position of OPC in a mix [23].

TABLE 2: SIEVE ANALYSIS RESULTS FOR GCHA AND OPC

Sieve size (µm)	Mass retained (g)		% retained		Cumulative % passing		Cumulative % retained	
	GCHA	OPC	GCHA	OPC	GCHA	OPC	GCHA	OPC
600	0.4	0	0.4	0	99.6	100.0	0.4	0.0
425	1.2	0.4	1.2	0.4	98.4	99.6	1.6	0.4
300	2.4	1.5	2.4	1.5	96	98.1	4	1.9
212	3.1	2.9	3.1	2.9	92.9	95.2	7.1	4.8
150	4.1	3.6	4.1	3.6	88.8	91.6	11.2	8.4
75	15.8	18.9	15.8	18.9	73	72.7	27	27.3
63	29.1	28.9	29.1	28.9	43.9	43.8	56.1	56.2
PAN	43.9	43.8	43.9	43.8	0	0.0	100	100.0
Total mass of each material = 100g R for GCHA = 11.2 R for OPC = 8.8								

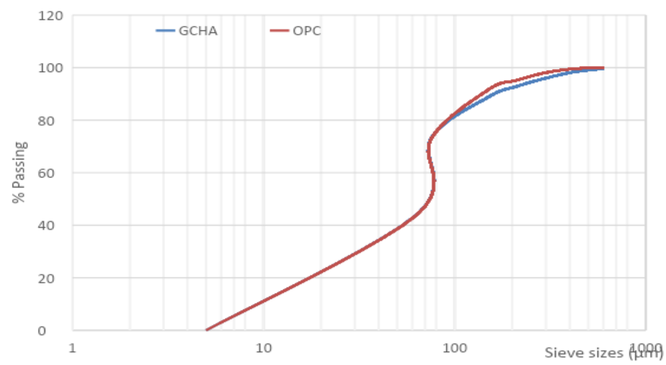

Fig. 7. Grading curve of GCHA and OPC.

C. *Workability and Density of Fresh GCHA concrete*

TABLE 3: RESULTS OF SLUMP TEST AND FRESH CONCRETE DENSITY

% GCHA	0	5	10	20	30	40
Slump (mm)	11	10	7	5	4.3	3.6
Fresh conc. Density (Kg/m^3)	2532	2529	2516	2508	2489	2466

The Slump test results are shown in and Table 3 and Fig. 8 for fresh concrete. The values obtained show that the slump decreases with increase in GCHA content which peaks at 0% with a decreasing density. All the values fall within the low range of slump [17]. Table 3 and Fig. 9 show the density values of the fresh GCHA concrete. It showed a declining state of values with increase in GCHA replacement. This will affect the strength values as they are most likely to decline.

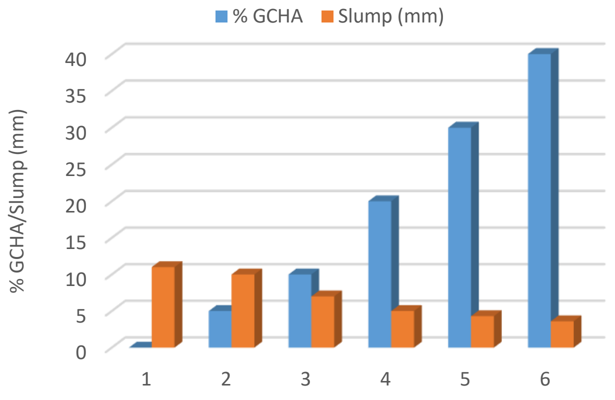

Fig. 8. Graph of Slump & % GCHA.

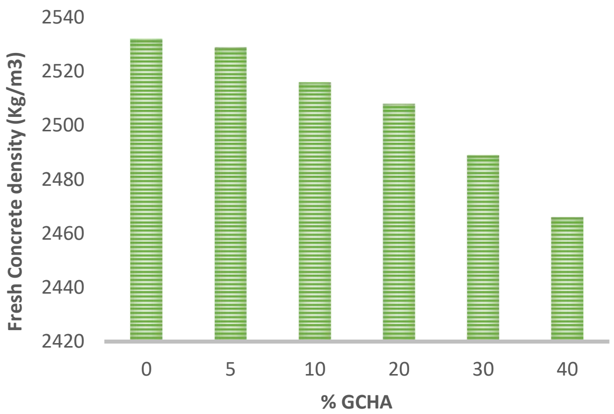

Fig. 9. Fresh Concrete Density Vs % GCHA.

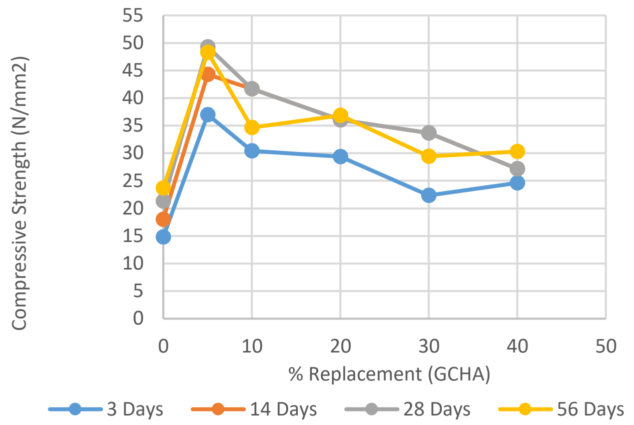

Fig. 10. Compressive Strength of GCHA Concrete.

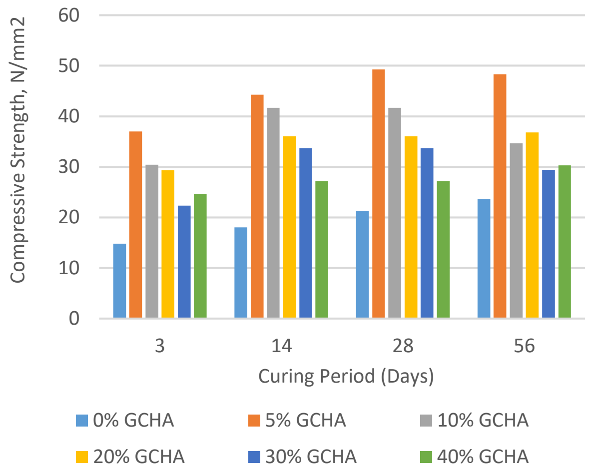

Fig. 11. Compressive strength trend of GCHA concrete.

D. Compressive Strength Test Result

Shown in Table 4 and Fig. 10 and 11 are the result of the Compressive Strength test. From the results, it is evident that the compressive strength for 3, 14, 28- and 56-days' period for plain concrete increases from 14.82, 18.03, 21.38, and 23.67 N/mm^2 respectively. However, as the percentages of GCHA increases, there is a corresponding decrease in the compressive strength. The exception is only with the 5% replacement of GCHA with a maximum value of 37.01, 44.29, 49.30 and 48.32 N/mm^2 for the 3, 14, 28- and 56-days' period respectively. This shows clearly that at 28 days, the maximum strength with 5% replacement with GCHA is 49.3 N/mm^2. The test results also reveal that the 30% replacement of GCHA for 3, 14, 28 and 56 days gave compressive strength values of 22.35, 22.35, 33.69 and 29.41 N/mm^2 respectively. These values are seen to be relatively higher than the values for plain concrete. This shows that 5-30 percentage replacement of GCHA is suitable for use in the production of concrete that can support heavy loadings in structures, [1].

TABLE 4: COMPRESSIVE STRENGTH OF GCHA CONCRETE (N/MM^2)

Curing period (Days)	**GCHA replacement level (%)**					
	0	5	10	20	30	40
3	14.82	37.01	30.45	29.36	22.35	24.64
14	18.03	44.29	41.68	36.04	33.69	27.2
28	21.33	49.3	41.68	36.04	33.69	27.2
56	23.67	48.32	34.68	36.84	29.41	30.31

E. Density Test Result

The Density values of hardened GCHA concrete are shown in Table 5 and in Fig. 12 and 13. At 5% and 10% GCHA replacement, the

corresponding densities were 2620 kg/m^3 and 2600 kg/m^3 at 14 and 56 days respectively, over plain concrete whose densities was 2580 kg/m^3 and 2560 kg/m^3 which generally shows an increase in densities at 5 to 10% replacement. Again, in general terms, density decreased with increase in GCHA replacement level from 20 to 40% replacements. This is in agreement with the values from fresh GCHA concrete and this will contribute to lower strength especially beyond the 10% replacement levels.

TABLE 5: DENSITY OF GCHA CONCRETE (KG/M^3)

Curing days	GCHA replacement level (%)					
	0	5	10	20	30	40
3	2560	2450	2390	2570	2440	2450
14	2580	2620	2540	2520	2540	2490
28	2590	2520	2540	2520	2540	2490
56	2560	2450	2600	2520	2410	2400

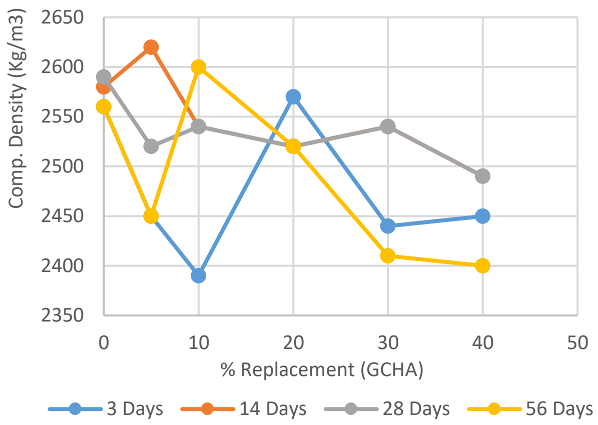

Fig. 12. Density of Hardened GCHA Concrete.

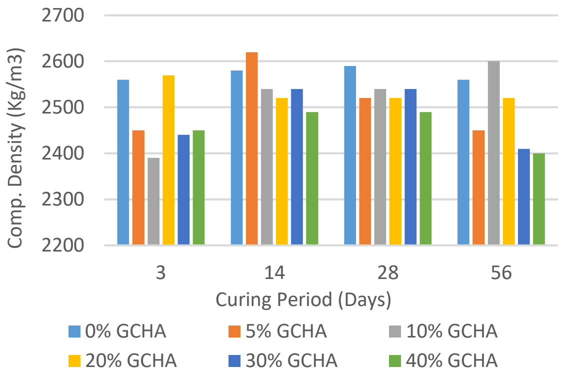

Fig. 13. Density trend of GCHA Concrete.

F. *Crack Measurements*

The crack measurements results are shown in Table 6 and Fig. 14 below. From the results, it is observed that only the 14-day cured GCHA concrete samples showed reductions in crack length (CR_L) and crack width (CR_W) respectively over plain concrete. This is the case for all the replacement levels with maximum 17.2% and 20.91% crack length and width differences respectively. A similar result on replacements with mineral admixtures of metakaolin and silica fumes gave crack width reduction of up to 110% for silica fume replacement level of 15% [24]. However, at 3, 28 and 56 days, the crack values largely increased with increase in GCHA except at 28 days which showed an initial crack width decrease from 1.77mm to 1.2mm at 30% replacement. Irrespective of curing days, it is observed that the CR_L generally decreased with age at replacement levels of up to 20% while CR_W followed a less uniform pattern. In all, GCHA concrete that is cured for 14 and 28 days show promise of crack control when the replacement level does not exceed 20%.

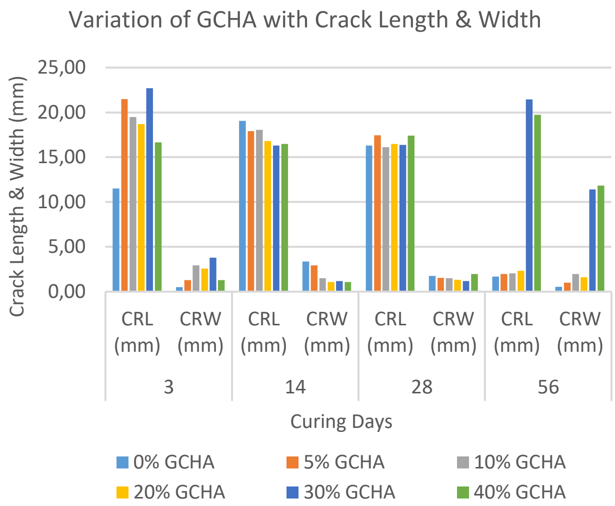

Fig. 14. Crack length and width of GCHA concrete.

TABLE 6: CRACK MEASUREMENTS OF GCHA CONCRETE (MM)

% GCHA	Curing duration (days)							
	3		14		28		56	
	CR_L (mm)	CR_W (mm)	CR_L (mm)	CR_W (mm)	CR_L (mm)	CR_W (mm)	CR_L (mm)	CR_W (mm)
0	11.5	0.5	19.1	3.4	16.3	1.77	1.68	0.55
5	21.5	1.3	17.9	2.9	17.5	1.5	1.98	1.01
10	19.5	2.9	18.1	1.5	16.1	1.5	2.05	1.97
20	18.7	2.6	16.8	1.1	16.5	1.3	2.32	1.61
30	22.7	3.8	16.3	1.2	16.4	1.2	21.4	11.4
40	16.8	1.3	16.5	1.1	17.4	1.97	19.7	11.8

IV. CONCLUSION

Based on the presented results, the following conclusions can be drawn:

- GCHA is a pozzolana with very high silica content and infinitesimal quantity of sulfate oxides that makes it useful in concreting for the partial replacement of cement.

- The concrete produced from GHCA possesses adequate compressive strength to bear load of structures just like the plain concrete.

- The GCHA concrete had crack length and width reductions when cured for 14 days and partially the same when cured for 28 days. However, theses were so at not more than 20% replacement levels.

V. RECOMMENDATIONS

GCHA can be used in partial replacement of cement in concrete production for strength with improvement in crack reduction if cured for 14 days at 5 – 20% replacement. Due to the zero-sulfate content of GCHA, it should find use in other durability considerations like containing expansion of hardened concrete. Further work on the optimum % replacement with GCHA for strength and durability (crack control) is recommended.

VI. Appendix

G. Appendix 1: UTM dashboard

H. Appendix 2: Weighing of beam

Appendix 3: Crack Measuring Microscope

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