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Flexural Strength of Concrete Made From Gunea Corn Husk Ash As Partial Replacement For Cement

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Research Article

Abstract

Guinea Corn Husk Ash (GCHA) was a converted product of Guinea Corn Husk (GCH) that was incinerated up to a temperature of 600^0C. The husk is a common agro-waste in Northern Nigeria. The GCHA was used to partially replace Ordinary Portland Cement (OPC) in concrete. The use was expected to reduce environmental nuisance and cost on cement. The replacement levels of 0%, 5%, 10%, 20%, 30% and 40% ash were used. The chemical constituents of the GCHA as determined from an X-Ray diffraction analyzer included SiO_2 (85.4%), K_2O (4.01%), Fe_2O_3 (0.64%), CaO (2.04%) and Na_2O (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 fall below the maximum allowable values of 4% and 1.5% respectively. The sieve analysis results show that GCHA has about the same fineness as OPC. The fresh concrete had slump values that ranged from 11mm for 0% cement replacement to 3.6mm for 40% replacement and lower densities. The hard concrete had flexural strength that was measured as Modulus of Rupture that ranged from the highest value of 4.61N/mm^2 at 0% replacement to the least value of 3.19N/mm^2 at 30% replacement after 56 days of curing. The density values equally decreased at an average of 3.3%. Relevant British and American standards procedures were used for the tests. The trend showed that GCHA neither improved flexural strength nor increased the density of concrete produced with it. The lower slump and fresh concrete values however makes for ease of fresh concrete handling.

Keywords
Guinea Corn, Husk Ash, Flexural Strength, Cement, Concrete, Pozzolana.

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1. Introduction

Guinea corn (Sorghum Vulgare) is one of the major cereal crops widely grown in the Northern Nigeria as an important staple food. The production rose from 11.5 to 11.7 million tons between 2010 and 2011 in the country. This is credited to improved varieties and demand from beverage and confectionary industries (Suleiman *et al*, 2012).

Presently there is a high agitation on the importance of environmental preservation and Guinea Corn Husk (GCH) as one of many agro wastes has very little economic value in Northern Nigeria where the crop is grown in large quantities and as such possesses serious environmental nuisance. The ways of their effective recycling and disposal are the subject of research efforts as provided in the following literature reviews:

When produced under controlled burning temperature, Guinea Corn Husk Ash (GCHA) has been found to be rich in Silica content giving it a pozzolanic property (Ndububa and Yakubu, 2015). A bio-chemical study on the GCH reported its very high silica proportion (Bello *et al*, *2018*).

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 (ASTM C311/C311M, 2018). This calcium hydroxide is liberated during the hydration of ordinary Portland cement (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 (Lea, 1970). The free CaOH are shown in the hydration equations of cement as given below (Neville, 2011):

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

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

Where, C_3S and C_2S are the Tricalcium Silicate and Dicalcium Silicate compounds in cement. $Ca(OH)_2$ is the free CaOH or lime.

Ashes from agro-waste materials have been used to produce concrete and mortar by partial replacement of OPC. A previous work showed that compressive strength of concrete made from GCHA improved at optimum replacement levels of 5 – 10% of OPC and depreciated in strength beyond that (Ndububa and Yakubu, 2015). 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% (Akinloye *et al.*, 2014). 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 (Ndububa *et al.*, 2015). Rice Husk Ash (RHA) is probably the most researched among the ashes from Agro-wastes. Reports on Rice Husk Ash (RHA) and others (Ujene and Achuenu, 2013) show that optimum replacement level are within the 5% bracket for improved compressive strength and split tensile test as in the case of RHA (Bhushan *et al*, 2017). 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 (Olutoge and Adesina, 2019). 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 (Mohammed *et al*, 2017).

The aim of the study is to investigate the impact of GCHA on the flexural strength of concrete. The objectives are to determine the chemical composition of GCHA, establish GCHA as a pozollana, determine the workability and density of fresh GCHA concrete and the flexural strength and density of the hardened GCHA concrete. Plate 1 shows a harvested bunch of guinea corn with the husk covering the seed.

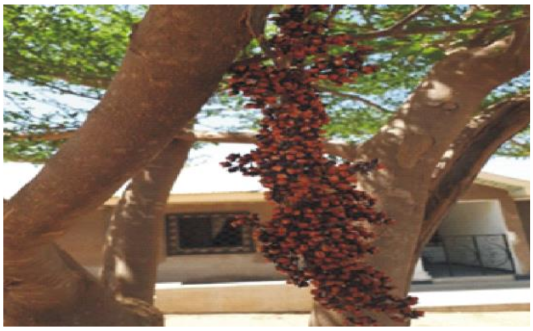

Plate 1: Outdoor storage of Guinea corn bunch

It is envisaged that with the use of the abundant supply of GCH especially during the postharvest season and when converted to GCHA as concrete material (in partial replacement of cement), the environment will be rid of a nuisance, farmers will find an economic way of the disposal and the cost of concrete may reduce. In this report, the replacement levels adopted were 0%, 5% 10%, 20%, 30% and 40% of GCHA over OPC by weight.

2. Materials and Methods

2. 1 Materials and their Preparations

The materials used were OPC, fine aggregates (river sand), coarse aggregates (crushed granite), water and GCHA. The OPC was obtained from the "Dangote" brand of Obajana plant in Kogi State Nigeria. The aggregates were obtained from the Kuje Area of Nigeria's Federal Capital Territory, Abuja. The aggregates were washed to remove silty and other deleterious materials and subsequently dried under sunlight. The fine aggregates were sieved to pass through the 200 µm and 63µm sieve sizes. The relevant procedures were derived from British Standards (BS EN 12620: 2002) and (BS EN A1, 2008).

GCH was obtained from Tukuba Village in the same Kuje Area. It is a post-harvest material by the local farmers after the seeds were extracted. It was burnt up in regulated temperature up to 600^{o}C in an incinerator (shown in plate 2) at Sheda Science and Technology Complex (SHESTCO) in Abuja and allowed to cool before grinding to fine powder into GCHA.

Plate 2: Carbolite incinerator/oven used to burn the husk

2.2 Chemical Analysis of GCHA

The chemical analysis of the ash (see plate 3) 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 (BS EN 196-1, 2016). The X-Ray diffraction method of analysis was used.

Plate 3: Bagging of Guinea corn ash

The Bogue composition equation was also used to compute the composition of Tricalcium Silicate (C_3S) and the Dicalcium Silicate (C_2S) in the ash. The composition equation is given as (Neville, 2011):

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

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

2.3 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 (BS EN 196-6, 2018), the % sample retained R was a measure of the Fineness, i.e.

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

2.4 Workability

Slump tests were carried out on each of the mix proportions of wet concrete in accordance with the relevant British standards (BS 1881 Part 102, 1991)

2.5 Flexural Strength Tests and Density

Modulus of Rupture (MOR) is derived from the Flexural strength test. Beams were cast from the samples into moulds of sizes 450 x 150 x 150 mm (ASTM C78/C78M, 2018). 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. To obtain the average MOR, three beams were then casted for each replacement level mixes to obtain the average values. The center-point loading was adopted as shown in Plate 4.

Plate 4: Flexural strength test

The MOR is then computed from the expression:

$$MOR = \frac{3PL}{(2bd^2)} \quad (6)$$

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.

2.6 Density Test

The first was the test on fresh concrete that was conducted in accordance with British standard (BS EN 12350-6, 2019) and another carried out on hardened concrete (BS EN 12390-7, 2019). In the later, the cube samples (3 for each experiment) were removed from the curing tank and the surface water allowed to drain off for 30 minutes, the cubes were then weighed. The average values of three samples were used.

$$Density = \frac{Mass\ of\ sample}{Volume\ of\ sample} \quad (7)$$

3. Results and Discussions

3.1 Chemical Analysis of GCHA

Shown in Table 1 is the result of the chemical analysis with the percent proportions of the oxide content.

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 (ASTM C311/C311M-18, 2018). This proves the suitability of GCHA as a pozzolana and confirms an earlier result (Ndububa and Yakubu, 2015). The non-detection of Sulphur trioxide (SO_3) content falls below the maximum specified content of 4%. An excess of SO_3 could lead to expansion and subsequent disruption of the set cement paste. The Na_2O 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 (Neville, 2011). The Loss on ignition content of 6.4% is well below the prescribed maximum value of 10%. The ash was therefore eminently qualified as a 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 rate of reaction, then very high content of it in GCHA will contribute to slower setting times when compared with 0% GCHA paste.

Table 1: Result of Chemical Analysis of GCHA

Oxide content	Si_2	Al_2O_3	Fe_2O_3	SO_3	Na_2O	K_2O	CaO	MgO	TiO_2	MnO_3	CuO	ZnO	L.O.I
% content	85.4	nd	0.64	nd	0.98	4.01	2.04	0.01	0.08	1.0	0.04	0.08	5.7

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
60	0.4	0	0.4	0	99.6	100.0	0.4	0.0
42.5	1.2	0.4	1.2	0.4	98.4	99.6	1.6	0.4
30	2.4	1.5	2.4	1.5	96	98.1	4	1.9
21.2	3.1	2.9	3.1	2.9	92.9	95.2	7.1	4.8
15	4.1	3.6	4.1	3.6	88.8	91.6	11.2	8.4
7.5	15.8	18.9	15.8	18.9	73	72.7	27	27.3
6.3	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								

3.2 Sieve Analysis and Fineness

The results of the sieve analysis of GCHA and OPC are shown in Table 2. The grading curves are shown in Figure 1. Comparing the similarity of the grading curves, it is evident that GCHA may be considered a filler material in addition to its pozollanic properties. The results revealed that the percentage of GCHA and OPC retained on sieve no. 7.5µm 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 place of OPC in a mix.

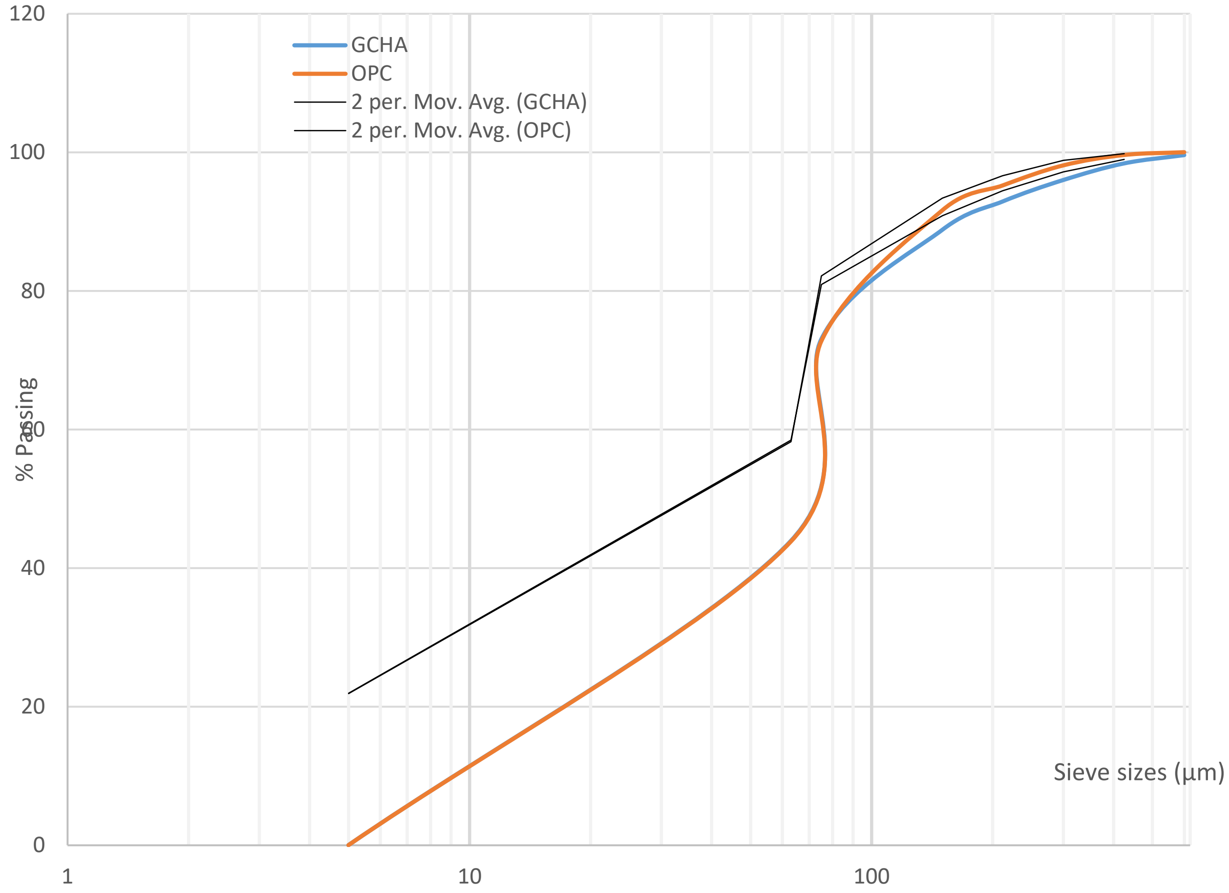

Figure 1: Grading curve of GCHA and OPC

3.3 Workability and Density of Fresh GCHA concrete

The Slump test result is shown in Table 3 for fresh concrete. The values obtained show that the slump decreased with increase in GCHA content. The highest slump value was with the sample without GCHA. All the values fall within the low range of slump (BS EN 12350-6, 2019). Table 3 also 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.

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 concrete density (kg/m^3)	2532	2529	2516	2508	2489	2466

3.4 Flexural Strength Test Result

Shown in Table 4 and Figure 2 are the result of the Flexural Strength test. The Modulus of Rupture generally increased with age up to 28days for samples of 10% and above of GCHA. There was a general decrease in MOR with increase in GCHA % replacement levels for each curing period. The results also show that optimum flexural strength is obtainable at about 5% replacement level. This is in the same range with results from a compressive strength test done earlier (Ndububa and Yakubu, 2015). Since the samples with 0% GCHA presented higher MOR values for all the curing periods and since MOR is a measure of elasticity of the sample materials, the trend therefore suggested that the GCHA pozzolana generally increased the brittleness of concrete.

Table 4: Modulus of Rupture of GCHA concrete (N/mm^2)

Curing period (Days)	GCHA replacement level (%)					
	0	5	10	20	30	40
3	4.05	3.63	2.43	1.96	1.18	0.43
14	3.67	3.44	2.76	2.05	1.6	1.04
28	5.4	5.35	4.8	3.45	3.32	2.12
56	4.61	3.94	3.56	3.9	3.19	3.48

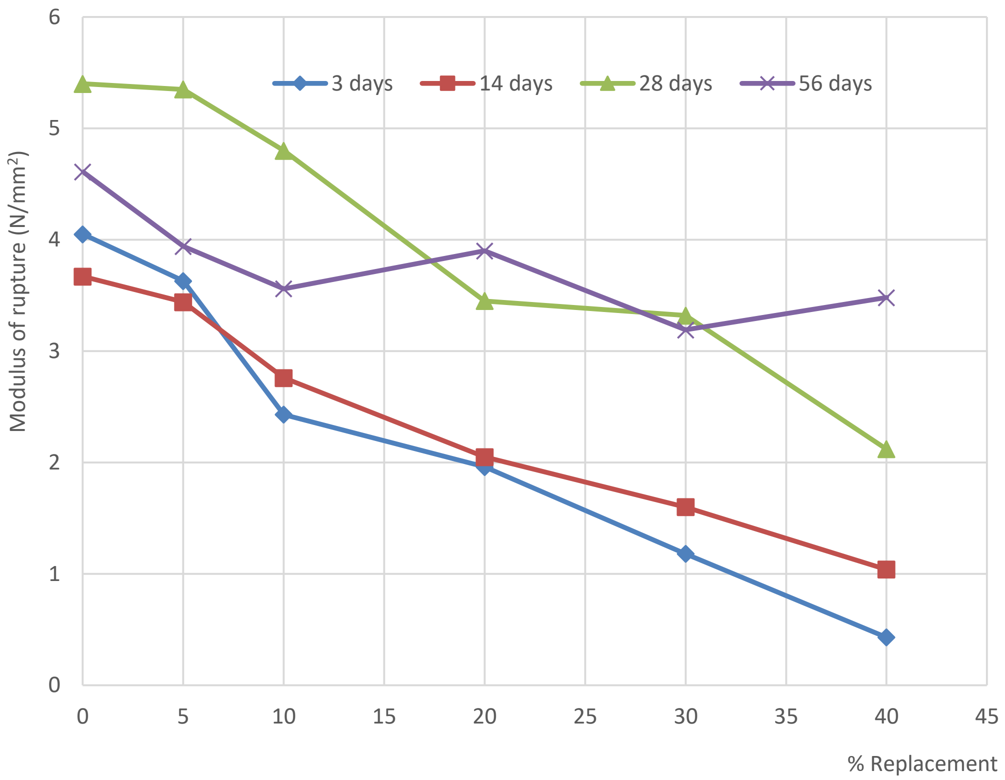

Figure 2: Flexural strength of GCHA concrete

3.5 Density Test Result

The density values of hardened GCHA concrete is shown in Table 5. While there was an increase of values with age in 0%, 20% and 40%, the case is not so for 10% and 30%. In the case of 5% GCHA, there was an increase in density up to 28days of curing period but it declined on the 56th day. Since the differences are slight, it may be safe to consider the trend as slightly increasing. Again in general terms, density decreased with increase in GCHA replacement level. This is in agreement with the values from fresh GCHA concrete. Again, this will contribute to lower strength especially beyond the 10% replacement levels. The trend is the same in previous works (Ndububa and Yakubu, 2015), (Ndububa.*et al*, 2015) where optimum values were found within the 5% and 10% range.

Table 5: Density of GCHA concrete (kg/m^3)

Curing period (days)	GCHA replacement level (%)					
	0	5	10	20	30	40
3	2540	2510	2540	2470	2480	2450
14	2520	2520	2540	2480	2490	2480
28	2540	2530	2490	2470	2450	2500
56	2560	2520	2500	2530	2470	2520

Figure 3 shows the flowchart depicting the flow of work that produced the manuscript. GC denotes Guinea corn and others were defined in the body of the manuscript

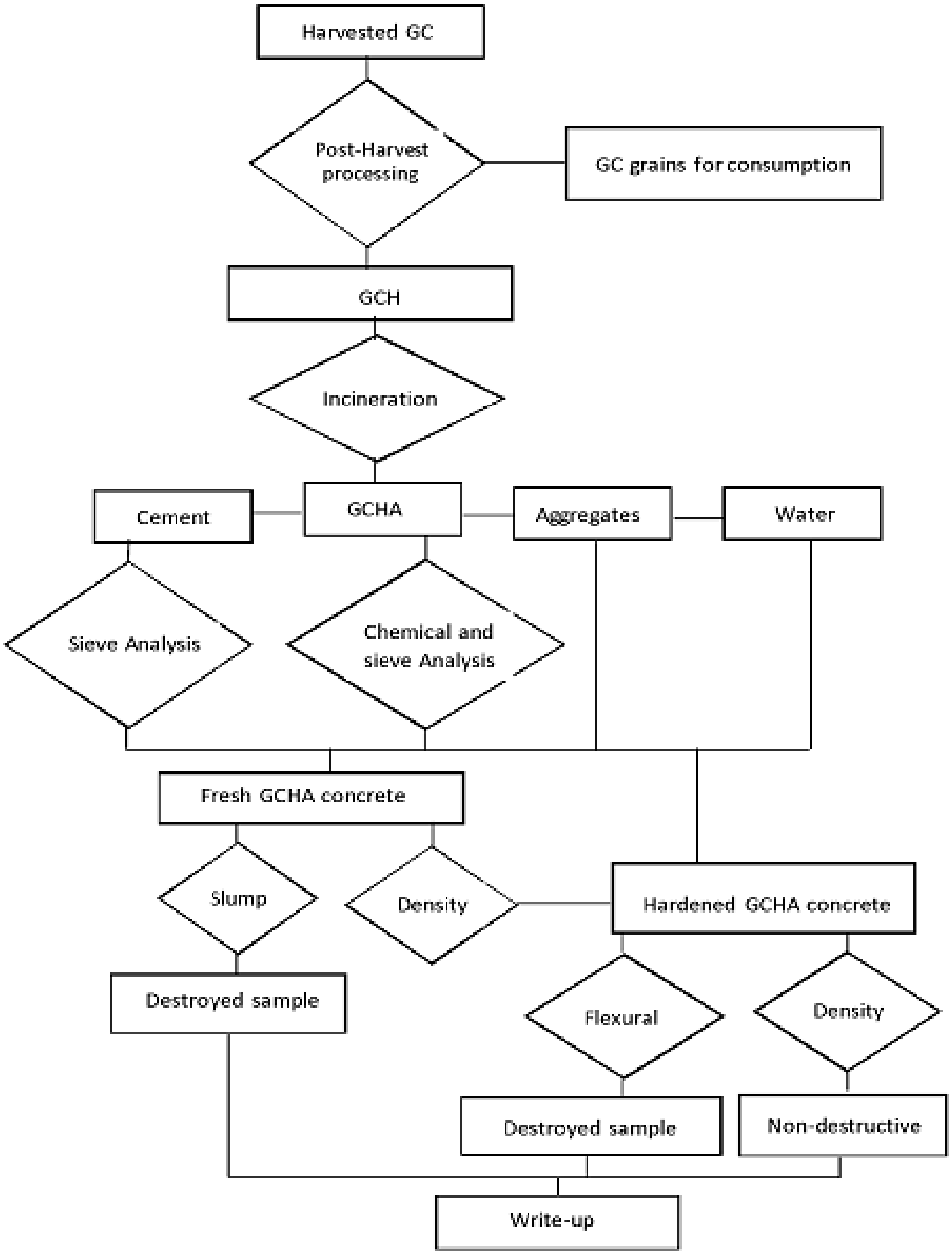

Figure 3: Flowchart of the work

4. Conclusion

From the results presented and discussed, the GCHA has a very high silica content that qualifies it as a high grade pozzolana. However the incorporation of GCHA as partial replacement for cement in concrete did not improve the flexural strength of the concrete. It may however improve other properties of concrete not reflected in this report.

The lower slump and density values of fresh GCHA concrete will accord it an advantage in handling over plain concrete. Since the densities of hardened GCHA concrete were generally lower than those of plain concrete, they are not expected to increase concrete strength. GCHA concrete may possibly find its use in durability considerations.

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