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A Study on Groundnut Husk Ash (GHA)–Concrete under Acid Attack

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Abstract: *This paper presents the findings of an investigation on the compressive strength of Groundnut Husk Ash (GHA)-Concrete and its resistance to acid attack. The GHA used was obtained by controlled burning of groundnut husk to a temperature of 600 ^oC and sieved through 75 µm sieve after allowing cooingl. The compressive strength of GHA-Concrete was investigated at replacement levels of 0, 5, 10, 20, 30 and 40 %, respectively by weight of cement. A total of ninety 150 mm cubes of GHA-Concrete grade 20 were tested for compressive strength at 3, 7, 28, 60 and 90 days of curing and the microstructure of GHA-Concrete samples at 0 and 10 % replacements were examined at 28 and 90 days of curing. Also, thirty six 100 mm cubes were subjected to attack from 10 % concentration of diluted solution of sulphuric acid (H_2SO_4) and nitric acid (HNO_3), respectively. The result of the investigations showed that the compressive strength of concrete decreased with increase in GHA content. However 10 % replacement with GHA was considered as optimum for structural concrete. GHA provided a less compact microstructure of concrete at 28 and 90 days curing compared to OPC concrete as a result of low pozzolanic activity. The use of GHA in concrete improved its resistance against sulphuric acid, but not against nitric acid attack. The average weight loss of GHA concrete after 28 days of subjection in sulphuric acid and nitric acid were 16.3 % and 17.3 %, respectively as opposed to 22.4 % and 15.1 %, respectively for plain Portland cement concrete.*

Key Words: *Groundnut Husk Ash, Concrete, Microstructure, Acid Attack*

I. Introduction

The durability of concrete is its ability to resist chemical and physical attacks that lead to deterioration of concrete during its service life. These attacks are leaching, sulphate attack, acid attack, carbonation, alkali-aggregate reaction, freezing-thawing and abrasion [1].

For a long time concrete was considered a very durable material requiring very little or no maintenance. Thus leading to the erection of concrete structures in highly polluted urban and industrial areas, harmful sub-soil water in coastal areas and other hostile conditions where other material of construction have not been found suitable. Though compressive strength of concrete is a measure of durability to a certain extent, but it is not entirely true that strong concrete is always durable, owing to some failures observed of concrete of high compressive strengths due to environmental conditions [2].

In recent years, durability is one of the critical issues to develop concrete technologies and construct reinforced concrete structures with long service life due to some economical and environmental reasons [1].

Supplementary cementitious materials have been identified in literature to be fundamental to advancing low cost construction materials with the main benefits of saving natural resources and energy as well as protecting the environment through the use of the main mineral admixtures [3]. [4] highlighted the effectiveness and durability of natural pozzolanic cement in ancient Greek and Roman structures built about 6th and 7th century BC and still in existence. Several experimental studies have been carried out on variety of pozzolanic materials such as volcanic ash, fly ash, blast furnace slag, silica fume, rice husk ash, sugarcane bagasse ash, sawdust ash, etc. However, there are controversial results about the resistance to acidic attack on pozzolanic cements in technical literature. Acidic attack usually originates from industrial processes, but it can even be due to urban activity. [5] claim that pozzolanic cement has better durability characteristics against acid attacks, while [6] and others claim vice versa. This study has shown 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 [7]. Acids react with alkaline components of the binder (calcium hydroxide, calcium silicate hydrates and calcium aluminate hydrates) lowering the degree of alkalinity.

The use of Groundnut Husk Ash (GHA) as a supplementary cementitious material in concrete has been reported in [8] and [9]. They suggested that up to 10 % GHA content could be used as a partial substitute of cement in structural concrete. It is against this background that this research aimed to investigate the resistance of GHA-Concrete subjected to acid attacks.

II. Materials And Methods

2.1 Materials

Ordinary Portland Cement produced in Nigeria (Dangote brand), with a specific gravity of 3.14 was used. The chemical composition analysis of the cement is shown in **Table 1**. Sharp sand collected from River Challawa, Kano, Nigeria, with a specific gravity of 2.62, bulk density of 1899.50 kg/m^3, moisture content of 2.50 % was used. The particle size distribution of the sand shown in Figure 1, indicate that the sand used was classified as zone -1 based on [10] grading limits for fine aggregates.

The coarse aggregate is crushed granite of nominal size of 20 mm with a specific gravity of 2.7, moisture content of 1.30 percent and bulk density of 1500.0 kg/m^3. The particle size distribution is also shown in Figure 1.

Groundnut husk was sourced from Yakasai village, Kano State, Nigeria. The Groundnut Husk Ash (GHA) was obtained by a two-step burning method [11], where the groundnut husk was burnt to ash and further heating the ash to a temperature of about 600 ^oC in a kiln and controlling the firing at that temperature for about two hours and the ash was allowed to cool before sieving through 75 µm sieve. The GHA is of specific gravity of 2.12, bulk density of 835 kg/m^3, moisture content of 1.60 % and grain size distribution is shown in Figure 1. A chemical composition analysis of the GHA was conducted using X-Ray Flouresence (XRF) analytical method and shown in **Table 1**.

Table 1: Oxide Composition of OPC (Dangote Brand) and GHA

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	TiO_2	MnO	BaO
OPC	18.0	3.10	4.82	68.37	1.48	0.35	0.32	1.82	0.35	0.03	0.16
GHA	20.03	2.00	4.03	13.19	1.82	38.80	-	1.08	0.68	0.20	0.31
Oxide	V_2O_5	P_2O_5	ZnO	Cr_2O_3	NiO	CuO	SrO	ZrO_2	Cl	L.o.I	
OPC	0.03	-	-	-	-	-	-	-	-	1.27	
GHA	0.03	1.90	0.08	0.03	0.01	0.10	0.20	0.22	0.26	8.02	

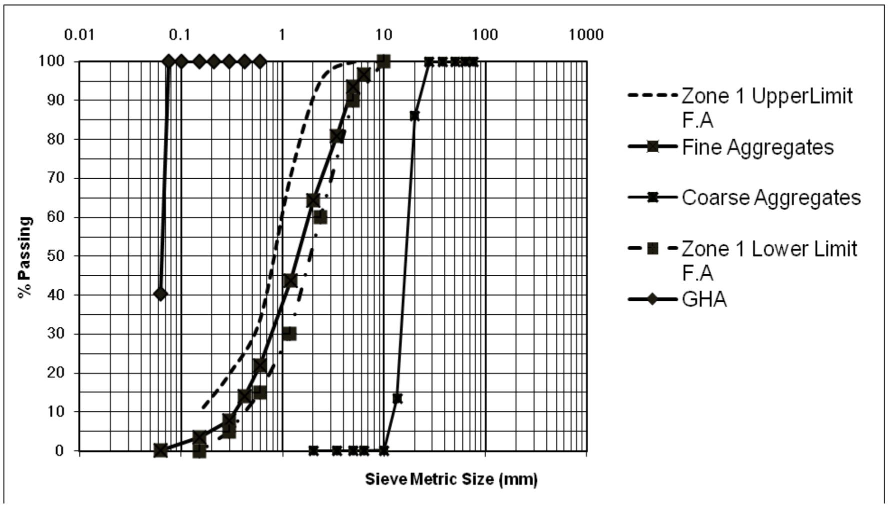

Figure 1: Particle Size Distribution of GHA, River Sand and Crushed Granite

2.2 Methods

2.2.1 Concrete Mix Design

Concrete grade 20 was designed with a target mean strength of 33 N/mm^2, slump range of 10-30 mm, and a water-cement ratio of 0.55. Six mixes as shown in **Table 2** were used, CM-00 is the control mix and CM-05, CM-10, CM-20, CM-30 and CM-40 are mixes containing GHA at replacement levels of 5, 10, 20, 30, and 40 %, respectively.

Table 2: Mix Proportion for Grade 20 GHA-Concrete

Mix No.	GHA (%)	Cement (kg/m^3)	GHA (kg/m^3)	Aggregates		Water (kg/m^3)	Water/cement ratio
				Fine (kg/m^3)	Coarse (kg/m^3)		
CM-00	0	318.2	0	704.5	1252.4	175.0	0.55
CM-05	5	302.3	15.9	704.5	1252.4	175.0	0.55
CM-10	10	286.4	31.8	704.5	1252.4	175.0	0.55
CM-20	20	254.6	63.6	704.5	1252.4	175.0	0.55
CM-30	30	222.8	95.4	704.5	1252.4	175.0	0.55
CM-40	40	191.0	127.2	704.5	1252.4	175.0	0.55

2.2.2 Compressive Strength Test on Groundnut Husk Ash (GHA)-Concrete

The compressive strength of GHA-Concrete was carried out using the mix proportions in Table 2. Samples were cast in steel cube moulds of 150 mm and cured in water for 3, 7, 28, 60 and 90 days, respectively. A total of ninety (90) cubes were tested and at the end of every curing regime, three samples were crushed in accordance with [12] using the Avery Denison Compression Testing Machine of 2000 kN capacity and at constant rate of 15 kN/s and the average taken. The result of compressive strength is shown in Figure 2.

2.2.3 Microstructure study of GHA-Concrete samples.

Crushed samples of GHA-Concrete from the compressive strength test were labeled and preserved for microstructure study of the concrete on the effect of GHA in concrete. The mixes considered were CM-00 and CM-10 at ages of 28 and 90 days, respectively. The study was carried out using a JOEL JSM 5900 LV Scanning Electron Microscope. The morphology of the concrete samples is shown in Figures 3- 6.

2.2.4 Test of GHA-Concrete in Acids.

The mix proportion of concrete shown in **Table 2** was used to determine the effect of acidic media on GHA-Concrete. Six mixes were used, CM-00, CM-05, CM-10, CM-20, CM-30 and CM-40. Concrete was mixed and cast in steel cube moulds of 100 mm during the casting of cubes for compressive strength test. A total of thirty six (36) cubes were cast and cured in water for 28 days. At the end of every curing regime, three samples were air dried, then weighed before immersing in 10 percent concentration of diluted solution of sulphuric acid (H_2SO_4) and nitric acid (HNO_3), respectively. The concrete cubes were weighed after immersion in acid solutions at 7 days interval until the 28th day to determine the weight of the samples after the acid degradation. The result of GHA-Concrete resistance to acidic solutions is shown in Figures 7 and 8.

III. Analysis And Discussion Of Results

3.1 Compressive Strength of GHA-Concrete

Figure 2 is result of compressive strength of GHA-Concrete and shows that compressive strength increased with age of curing but decreased with increase in GHA content at all curing ages. The 28 days compressive strength of GHA-Concrete ranged from 28.2 – 91.1 % of control at GHA content of 5 – 40 %, with least compressive strength occurring at 40 % GHA content. It was however observed that the 28 days compressive strength of concrete with up to 10 % GHA content exceeded the design characteristic strength. The decrease in compressive strength of concrete with increase in GHA content could be due to the fact that partial replacement of cement with GHA caused a reduction in the quantity of cement in the mix available for the hydration process and hence a reduction in the formation of the stable strength producing cementitious compounds, consistent with [13] explanations. The formation of secondary C-S-H gel as a result of pozzolanic reaction of GHA is weaker than that from cement hydration as inferred from [14] working on agroresidual waste in blended cement. Also for constant water/binder ratio, the loss in slump with increase in GHA content reduced the compaction of the concrete which may result in reduction in strength.

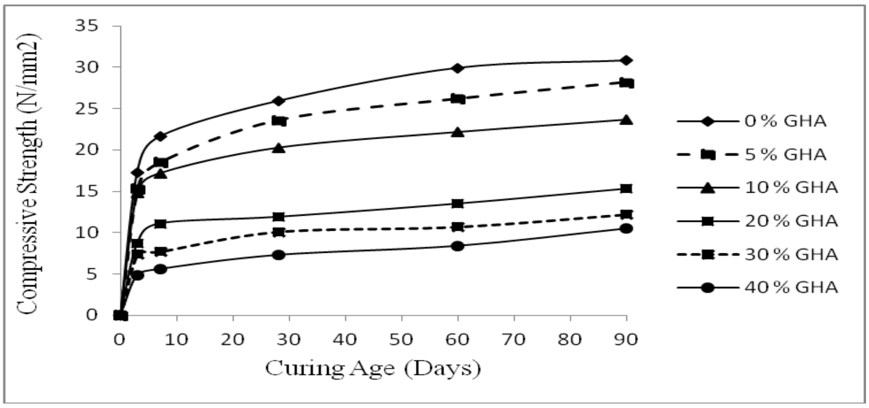

Figure 2: Compressive strength of GHA- Concrete grade 20

3.3 Microstructure of GHA-Concrete Samples

At 28 days of curing, the Scanning Electron Microstructure (SEM) photograph of the plain OPC concrete sample (Fig. 3) showed high content of C-S-H and $Ca(OH)_2$ as a result of hydration as well as large voids and some anhydrous cement particles. On the other hand, the SEM picture of 10 % GHA-Concrete (Fig. 4) indicated less formation of C-S-H and more large voids as well as more spots of anhydrous cement particles compared to plain OPC concrete. This was due to low pozzolanic reaction of GHA with consequence lower strength of concrete and an increase in porosity of the concrete compared to control.

At 90 days of curing, the SEM photograph of plain OPC concrete (Fig. 5) showed reduction in the voids in the concrete as more compact fibrous C-S-H are formed in the mature concrete as well as smooth platy crystals of $Ca(OH)_2$ giving a more compact matrix. However, a few bright particles of anhydrous cement were still observed. In the case of 10 % GHA-Concrete, the SEM photograph (Fig. 6) captured less C-S-H, larger voids and plates of $Ca(OH)_2$ and bright spots of anhydrous cement particles than that of plain concrete. The image however showed a more compacted microstructure than that at 28 days of curing of 10 % GHA-Concrete. This improvement is due to hydration and pozzolanic reaction of GHA.

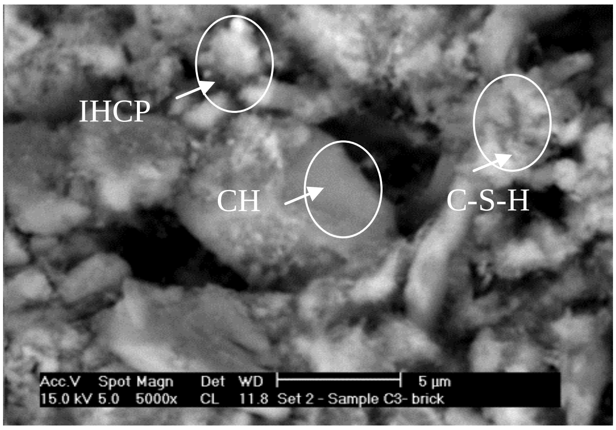

Fig. 3:SEM of OPC Concrete at 28 days,

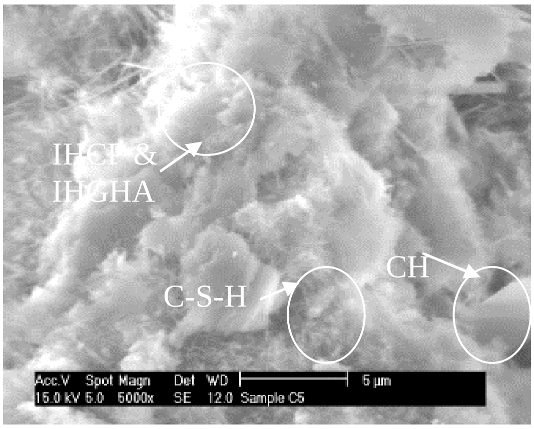

Fig. 4:SEM of 10% GHA-Concrete at 28 days

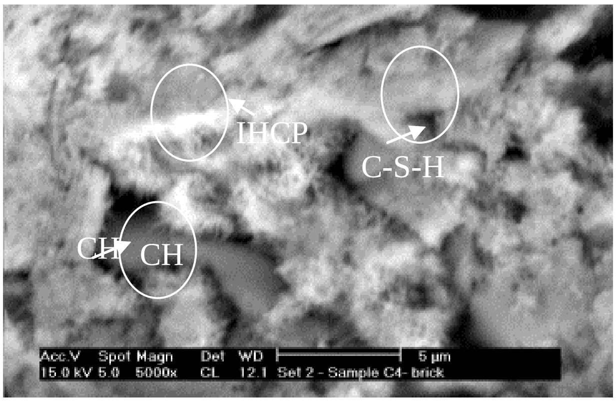

Fig. 5:SEM of OPC Concrete at 90 days,

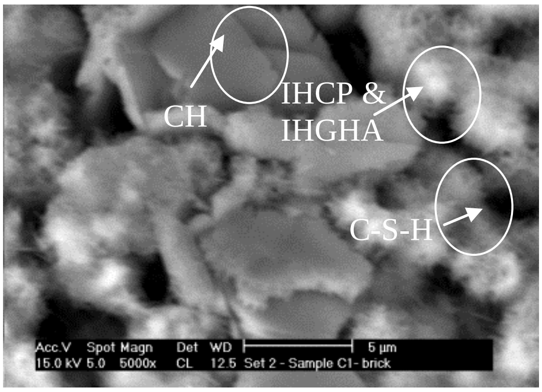

Fig. 6:SEM of 10% GHA-Concrete at 90 days

3.4 Effect of Acids on GHA-Concrete

The effect of 10 % concentration of sulphuric acid (H_2SO_4) and nitric acid, respectively on GHA-Concrete shown in terms of weight retained, in Figures 7 and 8, showed that concrete with GHA offered better resistance to deterioration by H_2SO_4 than Portland cement concrete, while plain Portland cement concrete performed better than GHA concrete in a nitric acid medium. The average weight loss of GHA concrete after 28 days of immersion in sulphuric acid and nitric acid were 16.3 % and 17.3 %, respectively as opposed to 22.4 % and 15.1 %, respectively for plain Portland cement concrete.

The enhanced resistance of GHA-Concrete to Sulphuric acid could be due to depletion in the $Ca(OH)_2$ content released from the hydration process and consumed in the GHA pozzolanic reaction, with less $Ca(OH)_2$ left to react with Sulphuric acid or due to less C_3A available to form the more disruptive ettringite in the GHA-Concrete, as well as noted in [15], the calcium sulphate salt formed from the chemical reaction is less soluble in water when compared to calcium nitrate, and this accounts for better resistance of the concrete to Sulphuric acid even though it is a very strong acid. On the other hand, the poor resistance of GHA-Concrete to nitric acid attack when compared with plain OPC concrete could be attributed to incomplete pozzolanic reaction of GHA after 28 days curing in water, as [16] reported that the replacement of OPC by a pozzolanic material usually has beneficial effect on cement durability at ages up to 1.5 years. Also, pozzolanic reaction usually reduces the $Ca(OH)_2$ available for reaction with acids, but GHA with a high content of CaO (13.19 %) may produce additional $Ca(OH)_2$ for reaction with HNO_3 to produce aqueous calcium nitrate salt which is deleterious in concrete. The high content of K_2O (38.80 %) in GHA may also be a source of disruption in GHA-Concrete as K_2O react with HNO_3 to produce potassium nitrate salt with adverse effect on the concrete. It was noted that 10 % concentration of solution of Sulphuric and nitric acids were very aggressive media with significant detrimental effect on GHA-Concrete grade 20.

The results have also shown that Sulphuric acid (H_2SO_4) is more aggressive to plain Portland cement concrete than Nitric acid (HNO_3), while GHA-Concrete was more resistant to sulphuric acid than nitric acid.

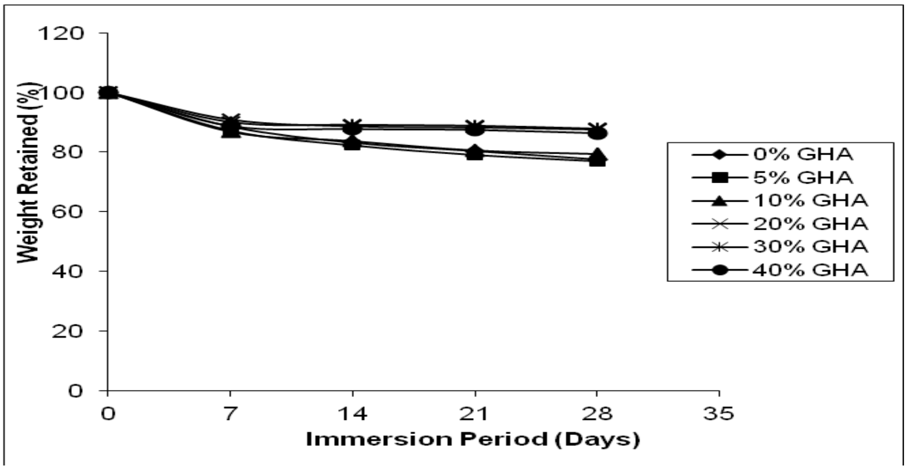

Figure 7: Weight of GHA-Concrete immersed in H_2SO_4 medium.

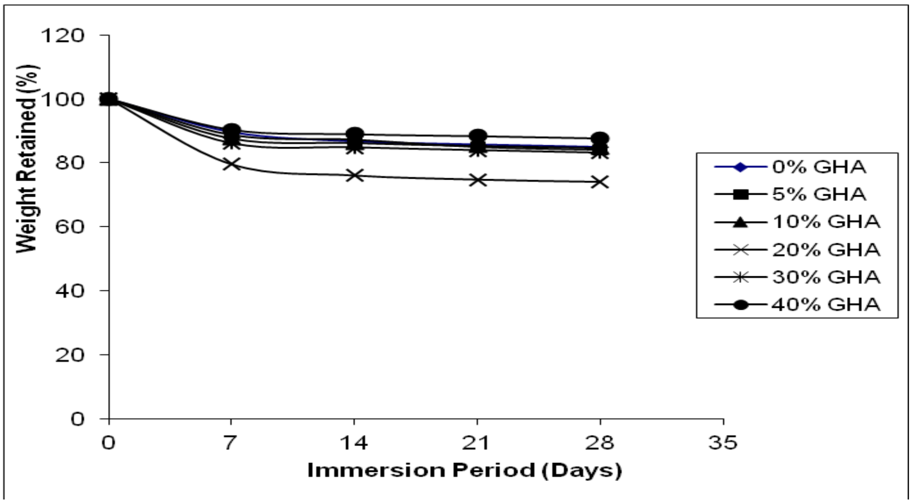

Figure 8: Weight of GHA-Concrete immersed in HNO_3 medium

IV. Conclusions

i) The compressive strength of concrete decreased with increase in GHA content. However, 10 % would be considered as the optimum percentage replacement to act as a retarder suitable for hot weather concreting, mass concrete and long haulage of ready mixed concrete.

ii) GHA provided a less compact microstructure of concrete at 28 and 90 days curing compared to OPC concrete as a result of low pozzolanic activity.

iii) GHA improved the resistance of concrete against sulphuric acid degradation, but concrete containing GHA was more susceptible to nitric acid attack.

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