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Evaluation of Guinea Corn Husk Ash as Oil-Well Cement Slurry Extender

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Abstract

Background: *Properly designed slurries for optimal cementing operations in oil and gas wells require additives to control properties such as density, free fluid, compressive strength, rheology, among others. These additives are imported though Ghana produces large amount of agro-waste annually and could be enhanced as cement slurry additives. The extender is one of such additives.*

Objective and Method: *This paper evaluates the effect of guinea corn husk ash as an extender on the properties of class G cement slurries using API RP10B standards. Prepared slurry samples were subjected to rheological, free fluid and density tests and the compressive strength of cured mould were determined.*

Results and Conclusion: *The ash showed improvement in the compressive strength with all the samples recording values above the minimum 10.3 MPa recommended by API RP10B. The rheological properties recorded viscosity values below 50 cP confirming the good pump-ability of the slurries. The decrease in free fluid content as concentration of ash was increased is indicative of the potentials of the ash to ensure stability of the slurry during cementing operations. The guinea corn husk ash, a product developed from agro-waste showed potential properties of an oil-well cement slurry extender and requires further research.*

Keywords: *Guinea Corn Husk, Extenders, Pozzolans, Density, Free Fluid, Compressive strength*

1. INTRODUCTION

Extenders are a class of additives used in preparing cement slurry for cementing operations in the oil and gas industries. Classification of extenders based on it general use for increase in yield and decrease in density are in two folds that is; water based extenders which include bentonite and light weight aggregates which include natural and artificial pozzolans. They can also be used to prevent the cement particles from settling and separating water from the slurry [1, 2].

Pozzolans are siliceous and aluminous materials which in themselves have little or no cementitious properties. In finely divided form and in the presence of moisture they react with calcium hydroxide liberated from the hydration of cement to produce stable, insoluble silicate known as Calcium-Silicate-Hydrate (C-S-H) which is a very good bonding material [2, 3] as shown in **Equations 1** and **2.**

$$C_2S/C_3S + H_2O \xrightarrow[\text{(Cement Hydration)}]{} C\text{-}S\text{-}H + CH \qquad [1]$$

$$CH + \text{silica} + H_2O \xrightarrow[\text{(Pozzolanic Reaction)}]{} C\text{-}S\text{-}H \qquad [2]$$

Pozzolans can be divided into two groups: natural and artificial. Volcanic ash is an example of a natural pozzolan whereas fly ash and agricultural wastes ashes from rice husk and corn husk are examples of artificial pozzolans. The addition of pozzolans has been found to contribute to the performance of the cement slurry and reduce cost [3].

Nazir *et al.* [4] asserted that fly ash is the most widely used waste ash pozzolan. However, other alternatives such as waste ashes from agricultural materials can be used for economic and environmental benefits. Guinea corn is an important food crop produced in large quantities in the savannah belt of West Africa. It has an annual production of three hundred and twenty-four thousand (324 000) metric tons indicating a growth rate of 8.96 % in Ghana [5]. It is mostly harvested and processed manually for food and beverages, leaving the large volume of residue constituting waste in the farm, most of which are flared off in the preparation for subsequent farming season [3].

Guinea corn husk is an agricultural waste which covers the corn kernel. It contains high cellulose content. It has been exploited for different applications including the production of bioethanol, biogas and also used as feed for animals [6, 7]. In spite of having been associated with so many applications, it is among the causes of environmental pollution. It is a common practice to dispose of corn husk along with corn stalks and leaves either by burning or tilling into the soil in developing countries like Ghana [4, 8]. The chemical analysis of Guinea Corn Husk Ash (GCHA) showed that a combination of its constituents qualifies it as a pozzolan [3, 4] and as such can serve as an additive in the cement slurry for cementing operations in the oil and gas industries.

In order to ensure a sustainable environment, utilisation of agricultural wastes such as guinea corn husk is encouraged. This paper therefore evaluates the effect of guinea corn husk ash as oil cement slurry extender by conducting important tests on the cement slurries formulated with the ash. These tests which includes; slurry density, free fluid, compressive strength and rheology are key in assessing the properties of cement slurry before conducting cementing operations in the petroleum industry.

2. MATERIALS AND METHODS

2.1. Materials

The materials used for this experiment include; Guinea corn husk ash, Class G Portland cement and fresh water. Guinea corn husk was obtained from Nandom in the Upper West region of Ghana . Samples of the husks collected were burnt up to 600 ˚C using an electric furnace to produce the ash. The ash was allowed to cool and pulverised to obtain a fine texture with particle sizes of about 75 microns and below. The viscometer used for the rheological measurement, the digital compressive tester and the hydrometer were all calibrated accordingly to ensure the authenticity of the results, in addition the tests were repeated to verify and validate the results obtained. Figure **1** shows the guinea corn husk and ash developed.

2.2. Slurry Preparation

792 g of cement with 348.48 g of water was used in formulating four slurry samples. The ash was introduced to the slurry in the following concentrations: 1 %, 3 % and 5 % by weight of cement, thus 7.92 g, 23.76 g and 36.90 g respectively.

2.3. Density Test

The densities of the cement slurries were measured using a hydrometer and the results expressed in kilograms per cubic meter. The hydrometer's cylinder was filled to the brim with water. The prepared slurry was then poured into the sample cup attached to the device. It was then lowered into the cylinder filled with water. The water displaced indicated the density of the formulated slurry.

2.4. Free Fluid Test

The amount of free fluid is the measure of slurry stability. Prepared slurry of 760 g was transferred into a dry test flask and sealed to prevent evaporation. The slurry-filled flask was levelled, placed on vibration-free and level surface. The quantity of fluid that was accumulated on top of the slurry after two (2) hours was collected and measured in milliliters. This was repeated for the other formulations using the American Petroleum Institute (API) RP10B procedure and standards of testing. The measured values in milliliters were then calculated as a percentage using **Equation 3**. Where V_{ff} is the volume of the free water collected in milliliters, ρ is the specific gravity of the slurry, and m_S is the mass of the slurry in grams.

$$\%\ \text{Free Fluid} = V_{ff} * \frac{\rho}{m_s} \qquad [3]$$

2.5. Compressive Strength Test

Three cubes each were moulded using the formulations at 0 %, 1 %, 3 % and 5 % levels of the guinea corn husk ash. These moulds were cured for 8 and 16 hours at 60℃ and 80℃ each. The cured samples were crushed using Chandler Engineering Digital Compressive Strength Tester to obtain the average compressive strength. **Equation 4** was used to calculate the compressive strength. The compressive strength was tested using API *RP10B* procedure. **Figure 2** shows the cube moulds developed from the cement and guinea corn husk ash formulations.

$$\text{Compressive Strength (MPa)} = \frac{\text{Force (N)}}{\text{Area (square meters)}} \qquad [4]$$

2.6. Rheological Test

The rheological properties of the slurries were determined using Chandler Engineering Viscometer Model 3500. The dial readings at 300, 200, 100, 6 and 3 rpm were recorded respectively. The plastic viscosities and yield points were calculated using **Equations 5** and **6**

$$\text{Plastic Viscosity (PV)} = 1.5 * (\Theta_{300} - \Theta_{100}) \text{ dial readings} \qquad [5]$$

$$\text{Yield Point (YP)} = \Theta_{300} - \text{PV} \qquad [6]$$

Figure1. *Guinea corn husk and ash*

Figure2. *Moulds of cement and guinea corn husk ash*

3. RESULTS AND DISCUSSION

3.1. Density of Formulated Slurries

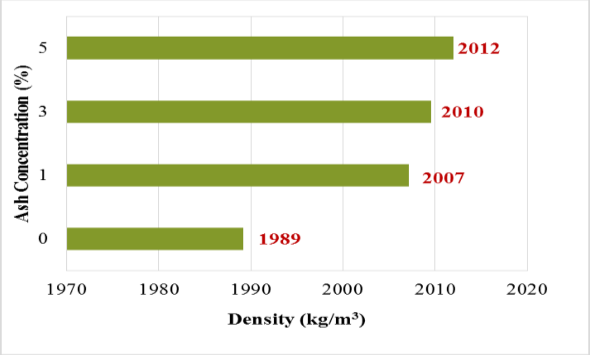

Figure3. *Density of cement slurry*

The results of the density test are shown in **Figure 3**. The density of the slurries slightly increased as the ash concentration increased. This trend is unexpected for pozzolanic extenders developed from agro-waste, and it could be attributed to the high solid content (75 um) of the ash developed. Though this contradicts the findings of Broni-Bediako *et al.* [1] and Ndububa and Nurudeen [3], where there was decline in density. With regards to Ndububa and Nurudeen [3], higher concentrations of ash (5%

to 25%) were used and the density of the cured moulds was measured instead of the slurry and this gave density values which decreased slightly with increase in ash concentration. In addition, for this study, the increase in density could be attributed to the formation of calcium silicate hydrate (C-S-H) from a chemical reaction between the SiO_2 and $Ca(OH_2)$ liberated during cement hydration. Thus as the ash increases, the strengthening gel (C-S-H) holds up the water thereby reducing the volume of water as the mass remains the same. This high solid content of the ash therefore increases the density of the slurry with increase in the ash concentration.

3.2. Free Fluid of Formulated Slurries

The results of the free fluid obtained from the slurries prepared are shown in **Figure 4**. The research revealed that increase in the ash concentration leads to a corresponding decrease in the accumulated free fluid on top the formulated the slurries. This decrease in free fluid formed with increasing ash concentration could be due to the gradual increase in the amount of calcium silicate hydrate (C-S-H) formed during cement hydration with the ash. The gel (C-S-H) holds up the excess water in the slurry to obtain a stable slurry. The free fluid accumulated on top the formulated slurries decreased from 5.9 % to 4 % when the ash concentration was increased from 0 to 5 %, this shows that, the ash has potentials to improve the stability of oil well cement slurries, though by recommended actual field application, the 4 % free fluid is considered high.

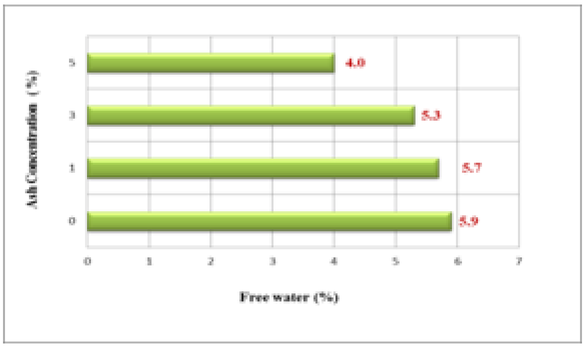

Figure4. *Free water from cement slurry*

3.3. Rheological Properties of Formulated Slurries

The rheological properties of oil well cement slurries are important in assuring that the slurries can be pumped into the well to achieve effective well cementing operation. Increasing the ash concentration resulted in decrease the Plastic Viscosities (PV) and increase in the yield points of the slurries. The decrease in plastic viscosities are as a result of the SiO_2 particles of the ash having a high air layer between them which increases compaction and decrease volume [9]. Thus the ash particles reduce the friction forces between the cement particles (dilatancy) due its shape and fineness. The Yield Points (YP) of the slurries also increases because the silicate (C-S-H) formed increases as the ash content increases, thereby creating a strong network of cement and ash particles. As such the threshold stress to overcome to initiate flow also increases. It is recommended that the plastic viscosity should be less than 100 cP to ensure a good pumpability of the fluid [10]. The results indicate that the slurries formulated using this ash has viscosities which were within the recommended values (**Figure 5**) showing it is desirable to pump such slurries and this confirms the findings of Abass *et al.* [10] and Broni-Bediako *et al* [1].

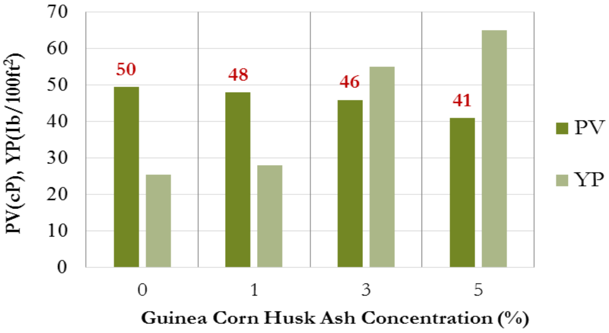

Figure5. *Plastic viscosity and yield point of slurries*

3.4. Compressive Strength of Cured Samples

Compressive strength of the cement plays an important role in the durability and quality of set cements and this is important in assessing the success or failure of any oil well cementing job. The plots of the compressive strength of samples cured at 60 ^{o}C (for 16 hours) and at 80 ^{o}C (cured for 8 hours) are shown in **Figures 6** and **7** respectively. At low concentration of the ash, the quantity of silica is low and this results in liberation of limited C-S-H though large quantity of $Ca(OH_2)$ is liberated from cement hydration. This phenomenon results in the decrease in the compressive strengths at 0 % and 1 % ash concentration levels. In addition all the cured samples met the minimum API *RP10B* standard requirement of 10.3 MPa (1500 psi) which was in conformity with the studies by Broni-Bediako *et al* [11]. It is therefore apparent that 3 % and 5 % concentration of ash produce optimal compressive strength. At high temperature, the solubility of $Ca(OH_2)$ decreases and this results in limited quantities of the C-S-H gel formation, which contributes to the decrease in compressive strength. This result is encouraging and indicative of the pozolanic ash produced from the agro-waste (guinea corn husk) could be used in enhancing the compressive strength of cementing in the Petroleum Industry. The detailed results for the compressive strength, free fluid and rheology are shown in appendices 1, 2 and 3 respectively.

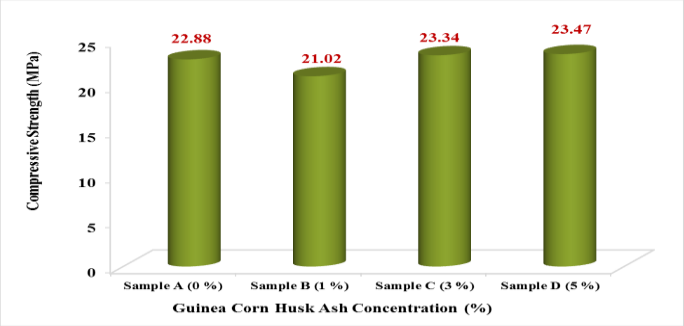

Figure6. *Compressive strength of moulds at 60˚C after 16 hours*

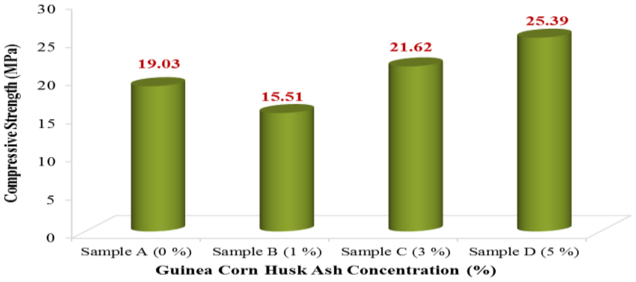

Figure7. *Compressive strength of moulds at 80˚C after 8 hours*

4. CONCLUSION

This paper investigated the effect of guinea corn husk ash (GCHA) on the cement slurry properties of class G Portland cement, which is used actively in cementing operations in the petroleum industry. The produced ash obtained at 600 ˚C in a furnace showed positive results. Evaluation of the properties of the formulated slurries using the ash and the class G Portland cement through a series of rheological and compressive strength tests as prescribed by API *RP10B*, shows positive results and the following conclusions can be drawn:

- The low plastic viscosity values obtained using the ash shows it is desirable to keep the cement slurry pumpable.
- The reduced free water content corresponding to increased ash concentration though still high for actual field applications shows the potentials of the ash to ensure stability of the slurry and this is an important property of cement slurry.
- The guinea corn husk ash enhanced the compressive of the moulds, and optimum compressive strength was attained when ash is used in concentrations of 3-5 %.
- The ash developed from the pozzolanic agro-waste (guinea corn husk) has the potentials of being used as extender in cement slurries, however further research is required to enhance this product.

ACKNOWLEDGEMENTS

Appendices

Appendix 1A, Compressive strength of GCHA-cement slurry at 60 ˚C after 8 hours.

GCHA (%)	Force (N)			Compressive Strength (Mpa)
	Cube 1	Cube 2	Cube 3	
Sample A (0 %)	31302	30573	28051	11.62
Sample B (1 %)	30226	25422	25306	10.46
Sample C (3 %)	25488	26329	31983	10.83
Sample D (5 %)	26454	29576	28139	10.87

Appendix 1B, Compressive strength of GCHA-cement slurry 60 ˚C after 16 hours.

GCHA Concentration (%)	Force (N)			Compressive Strength (Mpa)
	Cube 1	Cube 2	Cube 3	
Sample A (0 %)	66670	57431	53054	22.88
Sample B (1 %)	56786	51106	54864	21.02
Sample C (3 %)	60207	54371	66372	23.37
Sample D (5 %)	60580	64842	56283	23.47

Appendix 1C, Compressive strength of GCHA-cement slurry at 80 ˚C after 8 hours.

GCHA Concentration (%)	Force (N)			Compressive Strength (Mpa)
	Cube 1	Cube 2	Cube 3	
Sample A (0 %)	50719	45198	51417	19.030
Sample B (1 %)	33259	45452	41395	15.513
Sample C (3 %)	57449	57084	5287	21.622
Sample D (5 %)	57026	70717	68770	25.386

Appendix 1D, Compressive strength of GCHA-cement slurry at 80 ˚C after 16 hours.

GCHA Concentration (%)	Force (N)			Compressive Strength (Mpa)
	Cube 1	Cube 2	Cube 3	
Sample A (0 %)	67835	74623	58343	25.938
Sample B (1 %)	61203	43556	65189	21.952
Sample C (3 %)	74445	66323	83533	28.972
Sample D (5 %)	66932	67827	67195	26.083

Appendix 2, free fluid of GCHA-cement slurry.

Sample	A	B	C	D
Free Fluid (ml)	23.6	22.8	21.2	6
Free Fluid (%)	5.9	5.7	5.3	4

Appendix 3, Rheology slurries at room temperature

Ash Concentration (%) RPM	0	1	3	5
300	75	76	101	106
200	58	59	75	85
100	42	44	55	65
6	13	15	17	17
3	8	9	12	18
Plastic Viscosity (PV), cP	49.5	48	46	41
Yield Point (YP), Ib /100 ft^2	25.5	28	55	65

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