EVALUATION OF THE EFFECT OF WATER HYACINTH ASH (WHA) AS AN ADDITIVE ON LOCAL PORTLAND CEMENT FOR OIL WELL CEMENTING

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***Abstract*: Cementing operations is one of the most critical operations in drilling and completion of oil and gas wells. For these reasons, special additives are added to oilfield cements like class G cement to enhance its properties for specific well conditions. Generally, the additives and class G cement employed in the industry are not readily available in the Ghanaian market and are therefore imported, which comes as an added cost. This work therefore studied the effects of locally produced Water Hyacinth Ash (WHA) harvested from water bodies as additive to enhance the properties of local Portland cement for possible oil and gas well cementing operation. The Ash and local Portland cement were characterised using SEM, XRD and XRF. The Chandler Engineering Mixer Model 3060 was used for blending the cement slurry in accordance with API-RP-10B and ANSI/API Specification 10A at a cement to water ration of 0.46 and ash additive to cement in percentages of 1% – 5%. Rheological properties were done at 125.6 ºF. Curings were done at 140 °F at atmospheric pressure and at 3 000 psi and 170 °F at 3,000 psi. The results obtained were also compared with Commercial Silica (CS) used in the industry as additive to enhance cement performance at higher temperatures. From the results, the local Portland cement blended well with the WHA and CS. Also, the WHA compared favourably with the CS for all physical properties tested. It was established that the WHA gave an optimum result at a concentration of 2%. To help protect our water bodies, champion local content participation during cementing operations, it is recommended that WHA and local Portland cement should be used in cementing shallow wells respectively.**

***Keywords*: Cement, Free Water, Rheology, Compressive Strength, Water Hyacinth Ash**

Introduction

Cementing is one of the most critical steps in drilling and completion of oil and gas wells [1]. In High Pressure High Temperature (HPHT) environments, physical and chemical properties of cement are altered. Thus, special additives like silica flour/sand are added to prevent strength retrogression by improving the hydration chemistry where conventional additives have failed [2,3]. Research indicates that locally manufactured cements have shorter setting time or pump shorter than the imported class G. The high presence of the constituent, tricalcium aluminate ($3CaO.SiO_2$) in the local cements results in faster rates of reaction during their hydration period, causing the cement slurries to set at faster or shorter times than imported class G with lower tricalcium aluminate content [4]. This makes the local cement in its raw state not desirable for oil well cementing operations, though they are in abundance.

Pozzolanic action between calcium hydroxide ($Ca(OH_2)$) and agro-waste material formed a good cement bond [5]. The application of the agro-waste as cement property enhancer or partial replacement would help to reduce environmental pollution associated with the agro-waste disposal while promoting the local cement industry and generate revenue for other sectors of the economy [2,5].

Water Hyacinth with a relatively high ash content has become a nuisance in most of Ghana's water bodies. With the production of ash from this plant, a huge challenge in fishing and portable water production would be reduced. In Ghana, there exists few documentations on Water Hyacinth invasion [2,6,7]. However, globally, only few of the existing researches particularly discusses the effects of Water Hyacinth Ash (WHA) as cementing material. This study, therefore, assesses the effects of Water Hyacinth Ash as additive on local Portland cement for oil well cementing.

Materials and Methods

The water hyacinth was collected from River Volta, and ash at about 758 ˚C for 2 hours in a gas furnace. All cement slurry experiments were performed in line with API-RP-10B and ANSI/API Specification 10A requirement for materials and testing of oil well cement. The water hyacinth was charred into ash. Two local cements, GHACEM Cement (42.5R), Diamond Cement (42.5R) as well as WHA were characterised using XRF, XRD and SEM. Laboratory tests and data analysis were performed on the effect of the WHA on compressive strength, fluid loss, thickening time and rheological properties of the local cement. Results were compared with analysis using commercial silica. The ratio of water to cement used was 0.46 and a varying amount of additive was added to the mixture using Chandler Engineering Mixer 3060. This is illustrated in Table 1. The WHA and CS were varied in different concentrations of 1% to 5% at cement weight of 600 g for determining rheology (using rheometer), free fluid (using free water bottle), compressive strength (using Static Gel Strength Analyser), and thickening time (using consistometer). The pH of the slurry was also tested with a pH meter. Rheological properties were done at 125.6 ºF. Curing was done at 140 °F at atmospheric pressure and at 3,000 psi and 170 °F at 3,000 psi.

Table 1 Slurry Formulation

Additive (%) WHA/CS	Additive (g) WHA/CS	Cement (g)	Fresh Water (ml)
0	0	600	276
1	6	600	276
2	12	600	276
3	18	600	276
4	24	600	276
5	30	600	276

The free fluid of the various slurry samples was calculated using Equation 1:

$$\varphi = \frac{Vff \times S_g \times 100}{ms} \quad \text{Eqn. 1}$$

Where;
Vff is the volume of free fluid collected (supernatant fluid) expressed in millilitres; Sg is the specific gravity of slurry; ms is the initially recorded mass of the slurry in grams. The Plastic Viscosity and Yield Point were calculated using Equations 2 and 3 respectively:

$$\mu_p\ (cP) = 1.5(\theta_{300} - \theta_{100}) \qquad \text{Eqn. 2}$$
$$\tau_o\left(\frac{lb}{100ft^2}\right) = \theta_{300} - \mu_p \qquad \text{Eqn. 3}$$

Where; μ_p is the Plastic Viscosity; τ_o is the Yield Point, θ_{300} is 300 rpm dial reading; θ_{100} is 100 rpm dial reading

Results and Discussions

The chemical analysis of the local cement samples, WHA and CS and are shown in Table 2 and Figs. 1 to 5. SEM shows the morphology of the various samples, XRF shows the various elements present in the samples while the XRD indicates the minerals and peaks of the various compounds present in the samples.

Table 2 XRF of GHACEM, Diamond, Class G Cement, CS and WHA

Component	Composition (wt %)				
	GHACEM	DIAMOND	CLASS G	WHA	CS
CaO	53.43	60.31	64.2	5.25	0.29
SiO_2	21.62	18.74	21.6	48.33	94.74
Al_2O_3	4.80	4.97	3.3	8.34	0.99
Fe_2O_3	3.04	3.19	4.9	4.60	0.14
K_2O	0.68	0.42	0.64	10.25	0.98
SO_3	2.56	2.53	2.2	1.07	0.15
Na_2O	0.58	0.29	0.41	0.97	0.38
MgO	3.41	1.47	1.1	1.91	0.41
LOI	9.40	8.02	0.6	11.62	1.94
Cl				4.24	
TiO_2				0.46	0.01
Mn_3O_4				2.19	
P_2O_5				0.72	0.08

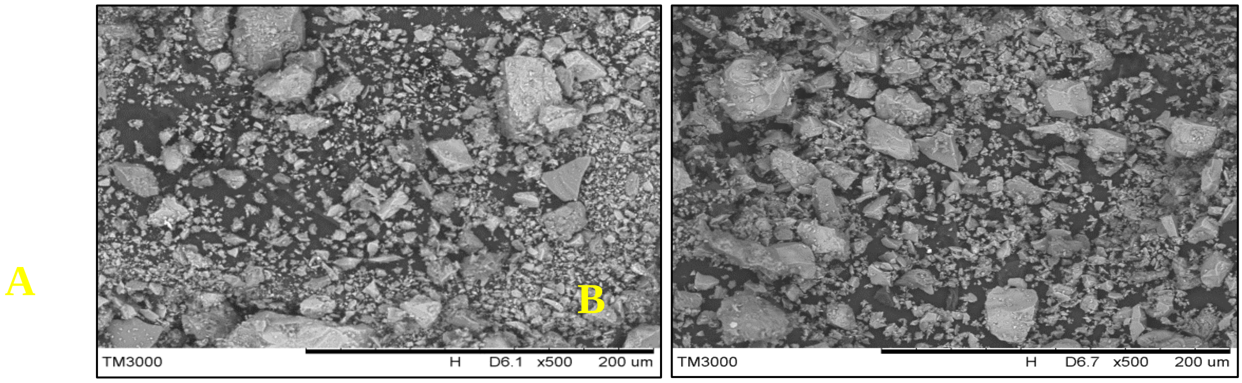

Fig. 1 SEM Photomicrographs of GHACEM (A) and DIAMOND (B) Cements

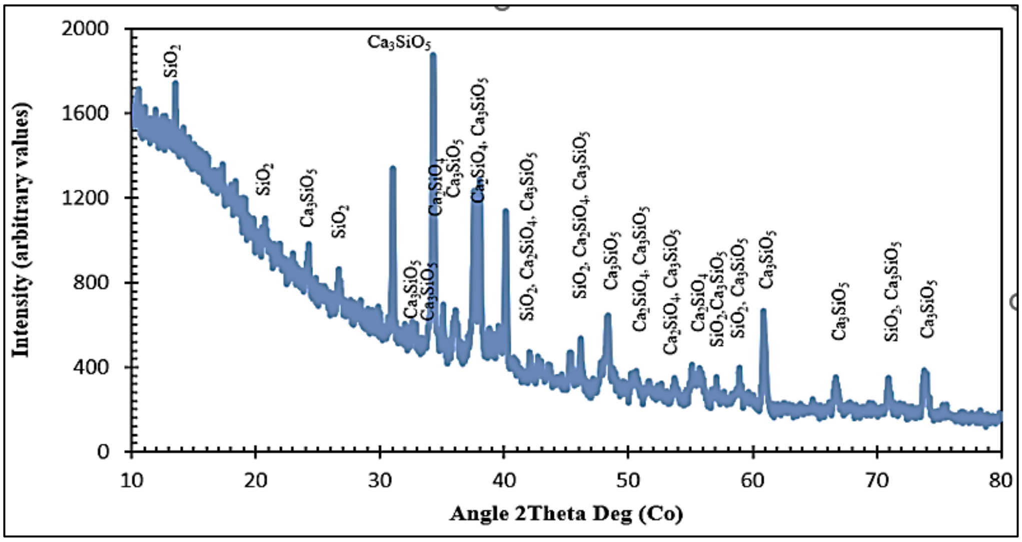

Fig 2 XRD Patterns of GHACEM Cement

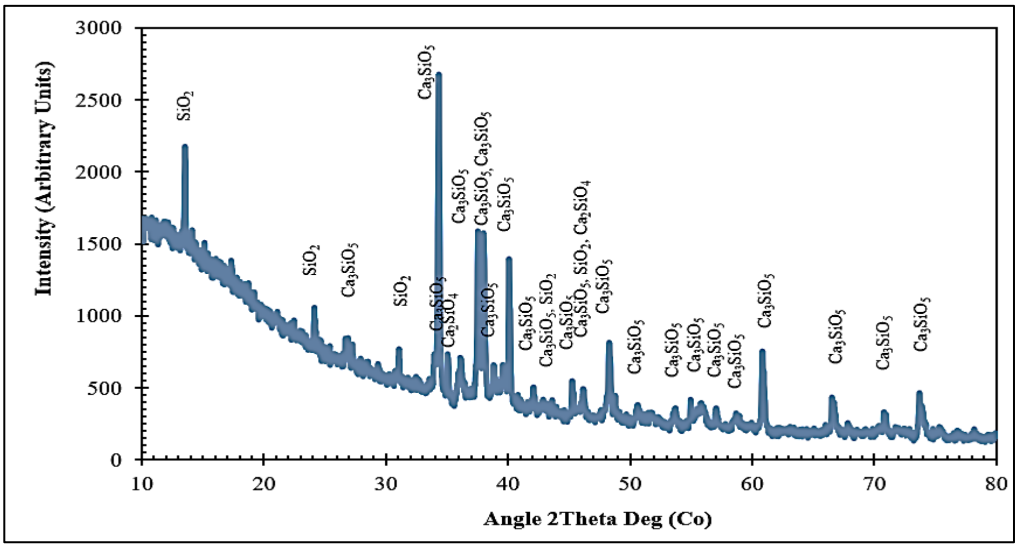

Fig 3 XRD Patterns of Diamond Cement

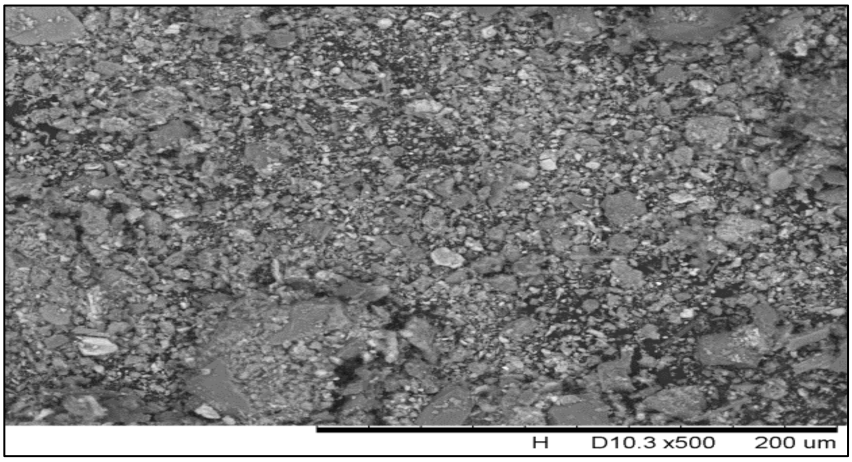

Fig. 4 SEM Photomicrographs of Water Hyacinth Ash

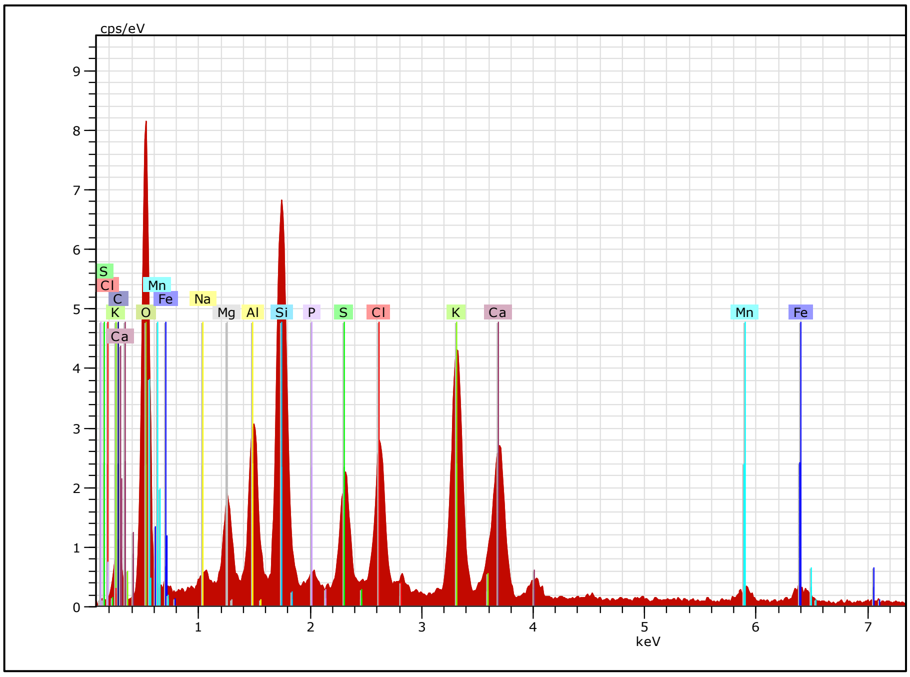

Fig. 5 XRD Patterns of Water Hyacinth Ash

Cement Selection (Diamond Cement)

The Diamond cement was chosen over the GHACEM cement for this work because of its higher Calcium Oxide (CaO) content (the main dominate material of cement) than reported in GHACEM which by its expanding agent helps cement slurry to control contraction as cement slurry sets (Fig. 6). It is also required to form silicates and aluminates of calcium. Deficiency in lime causes the cement to set quickly and also reduces the strength [9, 10]. Silica Dioxide (SiO_2) is also needed in sufficient quantity to form dicalcium and tricalcium silicate as it imparts strength to cement [10]. From Fig. 6, the concentration of the silicate is relatively good for all cement sampled though that of the GHACEM is better. However, higher content of Magnesium Oxide (MgO) mostly more than 2% in cement affect the soundness of the cement; this increases porosity of the cement thereby reducing its compressive strength [9]. GHACEM recorded a relatively higher values than the Diamond.

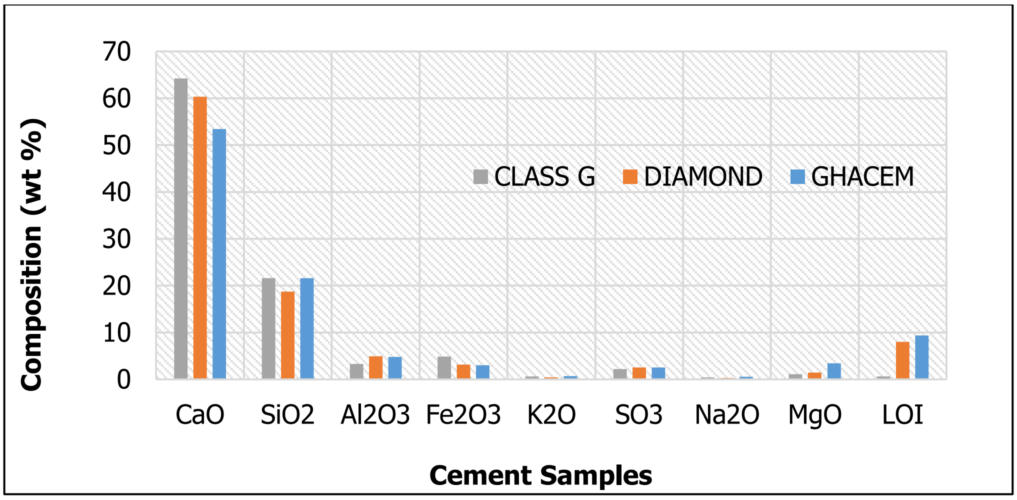

Fig. 6 Composition of Cement Sample

Rheological Properties

The rheological properties of the cement slurries were conducted at Bottom Hole Circulating Temperature (BHCT) of 80 °F. The rpm and the corresponding dial readings are recorded in Table 3 and their Plastic Viscosity and Yield Point calculated.

Table 3 Rheological Result Using Commercial Silica (CS)

RPM	Concentration of Commercial Silica (CS) % BWOC						Concentration of WHA % BWOC					
	0	1	2	3	4	5	0	1	2	3	4	5
600	95	104	113	124	131	137	95	104	124	121	126	128
300	66	78	84	92	96	104	66	77	92	89	94	101
200	56	66	71	79	80	85	56	65	79	74	78	88
100	44	52	55	60	63	66	44	51	60	58	63	72
6	13	20	20	23	23	23	13	21	22	22	22	26
3	11	14	15	15	14	14	11	13	15	15	17	17
PV	33	39	44	48	54	57	33	39	48	47	47	44
YP	33	39	41	44	42	47	33	38	44	43	48	58

The rheological properties of oil well cement is essential assuring that slurries can be mixed at the surface and pumped downhole with minimum pressure drop, hence achieving effective well cementing. The PV and YP increased with an increase in concentrations of WHA and CS when compared to the control. According to Shuker *et al*. [11], the problem associated with pumping cement slurry through wellbore comes about when rheological values are high. However, Abbas *et al*. [12], recommend that PV less than 100 cP ensures good pumpability of cement slurry. As shown in Figs. 7 and 8, the PV recorded for CS and WHA at BHCT of 80 °F indicated a good pumpability of the slurry and YP values calculated are higher than 15 Lb/100 ft^2 which prevents cement from settling [13], further proves that the slurry is pumpable. Moreover, from the test conducted, the WHA compared favourably with the CS being used in the oil industry.

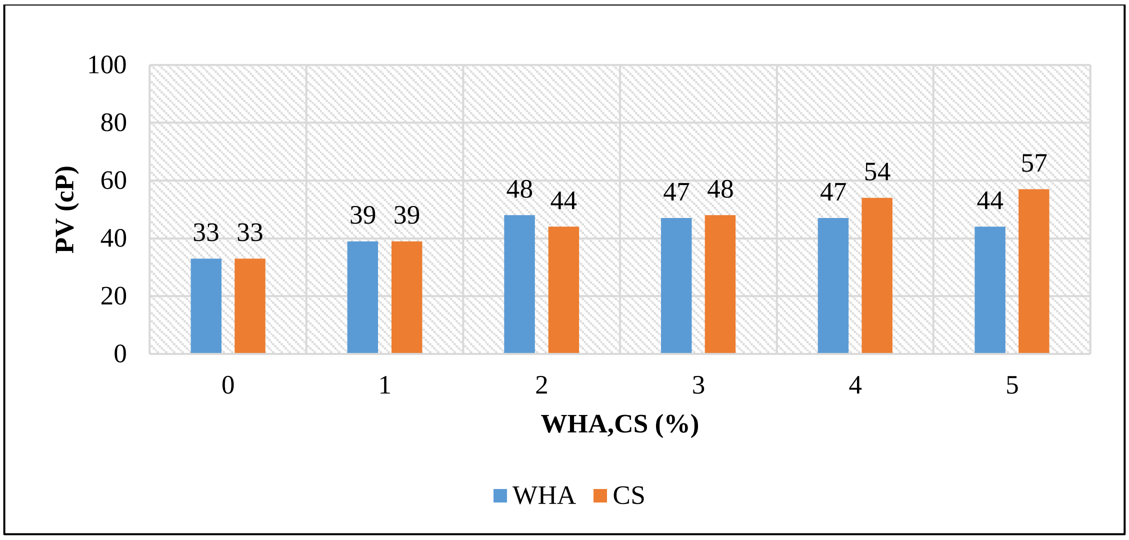

Fig. 7 Effects of WHA and CS on Plastic Viscosity (PV)

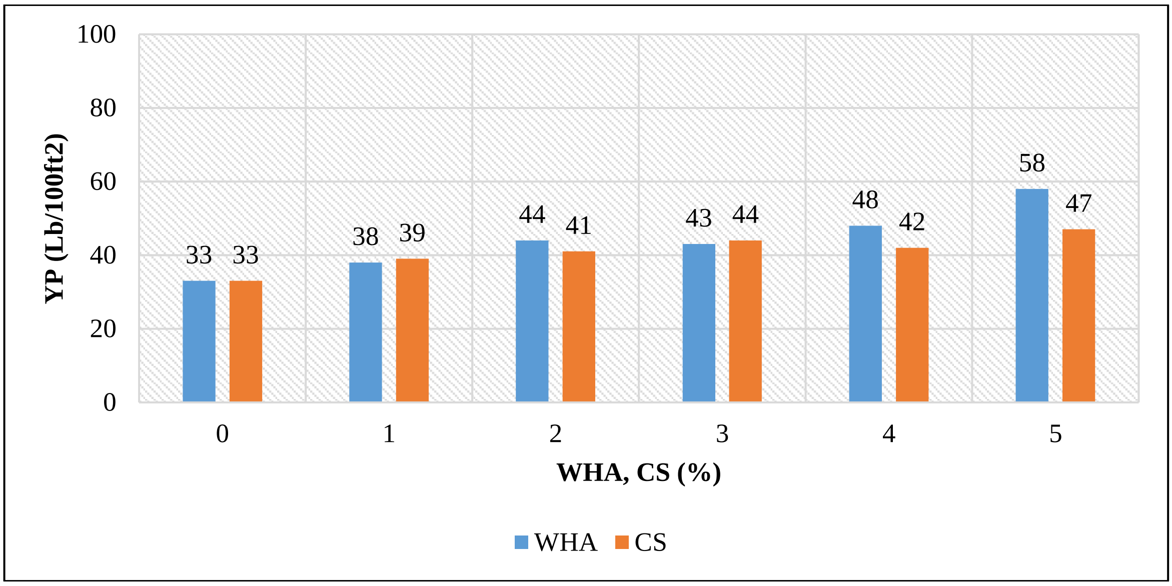

Fig. 8 Effects of WHA and CS on Yield Point (YP)

Free Fluid

The results of the supernatant fluid (Vff) were obtained at 80 °F and percentage of free fluid of the various samples were calculated using Equation 1. Free fluid should be controlled to prevent early hardening of slurry which could lead to secondary cementing. From industry practices, free fluid percentage should be less than 5.9%. As shown in Fig. 9, the CS and WHA to some degree have controllable amount of free fluid. An increase in concentration of the additives increased the amount of free fluid which peaked at 2% before dropping to lower values. The high value of free fluid recorded at 2% may be due to poor handling and exposure to moisture making it less stable when compared to the other concentrations. The high SiO_2 in the CS may have improved the free fluid of the control at an addition of 1%. Siliceous materials in the presence of moisture react chemically with Calcium Hydroxide ($Ca(OH)_2$) releasing hydration of Portland cement to form Calcium Silicate Hydrate (C-S-H) thereby absorbing water at a higher rate [4,13].

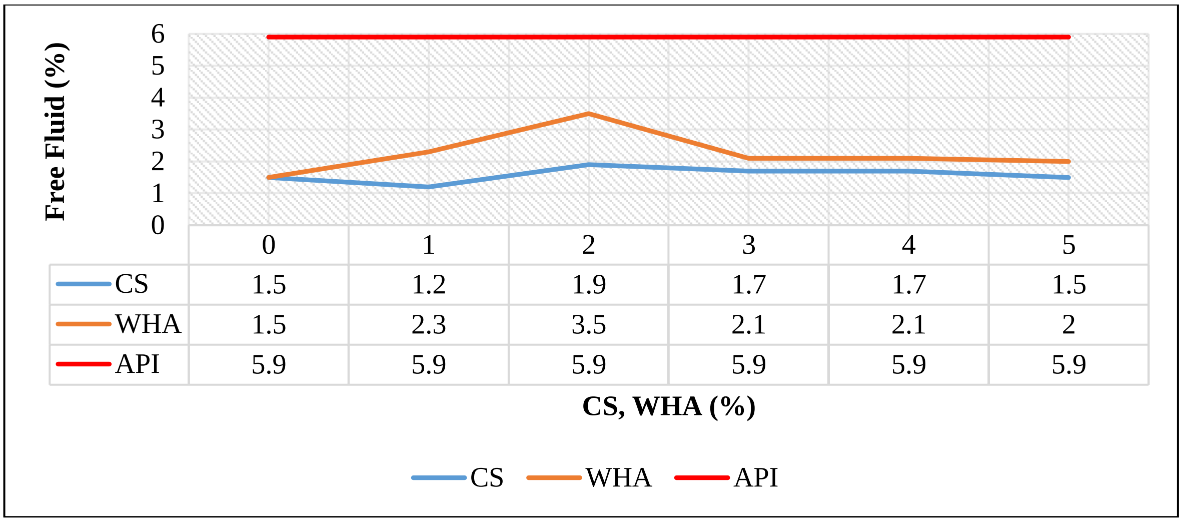

Fig. 9 Effect of CS and WHA on Free Fluid

Thickening Time

The thickening time was conducted at BHCT of 80 °F to know how long the slurry remains in the pumpable phase and this is represented in Figs. 10 and 11. Thickening time is the time after initial mixing when the cement can no longer be pumped is crucial in oil well cementing. If the thickening time is too short, the cement fails to reach its required placement and too long a thickening time results in costly delays. The introduction of the additives may have caused an increase in viscosity and decrease in thickening time. According to [14], addition of silica flour to slurry results in an increase in solid content which leads to reduction in thickening time. As shown in Figs. 10 and 11, the CS and WHA took shorter time to reach 30 Bc, 50 Bc and 100 Bc when compared to the control thereby acting as accelerators. An optimum concentration of 2% of WHA gave the least time for the slurry to reach 30, 50 and 100 Bc. The effect of WHA is prominent to a concentration of 2% (Fig. 11) and this may be due to the high amount of Al_2O_3 present in the WHA which is responsible for quick setting of cement [15, 10].

Also, the WHA took less time than the CS to finally set at 100 Bc for all concentrations tested. This could be attributed to the greater amount of P_2O_5 contained in the WHA than in CS since P_2O_5 can act as a desiccant and dehydrating agent [16].

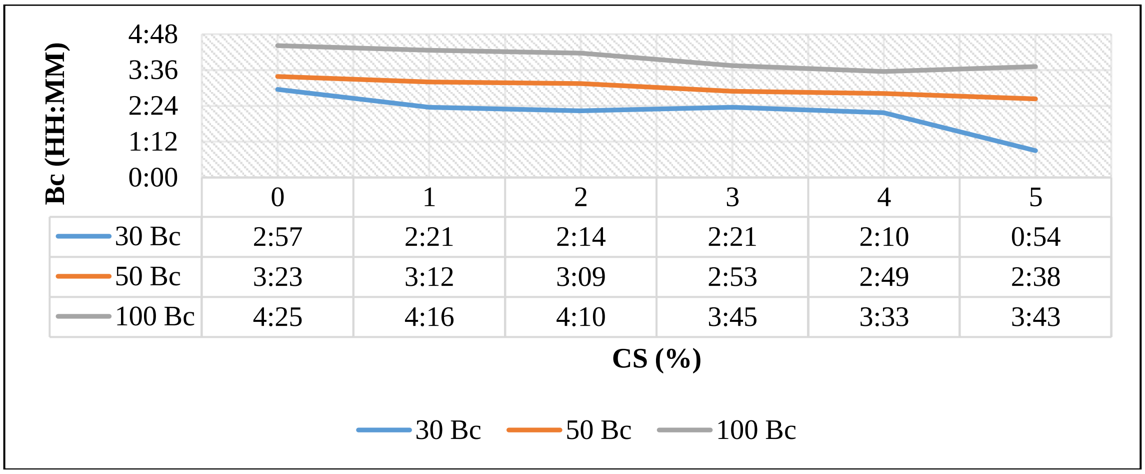

Fig. 10 Effects of CS on Thickening Time

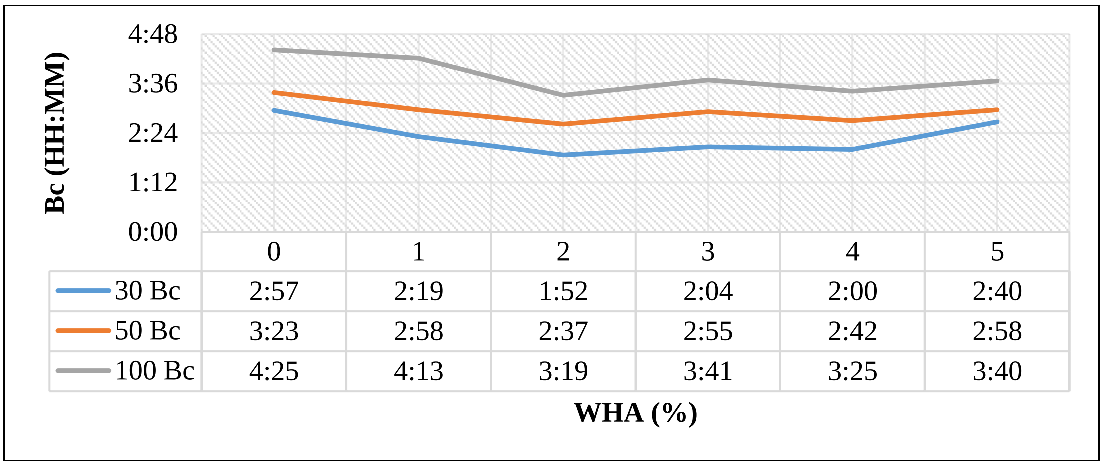

Fig. 11 Effects of WHA on Thickening Time

Compressive Strength

Compressive strength indicates the quality of the set cement. The compressive strength of the cement was tested at varying temperature and pressure as presented in Figs. 12 to 14. Higher compressive strength values mean low porosity and high resistant of cement. Mostly, industry practices accept a minimum compressive strength of 500 psi after 24 hours curing [17]. From the test, the CS and WHA produced a minimum compressive strength of 1,463 psi and 2 338 psi after 12 and 24 hours of curing which indicates a highly durable cement. At a concentration of 2%, the WHA recorded the highest compressive strength for all temperatures and pressures tested.

Although, the two additives improved the compressive strength of the control cement, the WHA performed better than the CS at tests conducted at 140 °F at atmospheric pressure (Fig. 12) and 140 °F at 3,000 psi (Fig. 13). This could be due to the greater amount of Titanium Dioxide (TiO_2) contained in the WHA than the CS (Table 1). According to Khushwaha et al. [18], 1% of TiO_2 (by weight) increases the compressive strength of concrete. But as temperature increased to 170 °F at 3,000 psi (Fig. 14), the CS performed better than the WHA which according to [3], silica causes the reaction with cement and water to produce xonotlite instead of tobermorite at high temperatures. Xonotlite is stronger and results in an enhancement of cement strength.

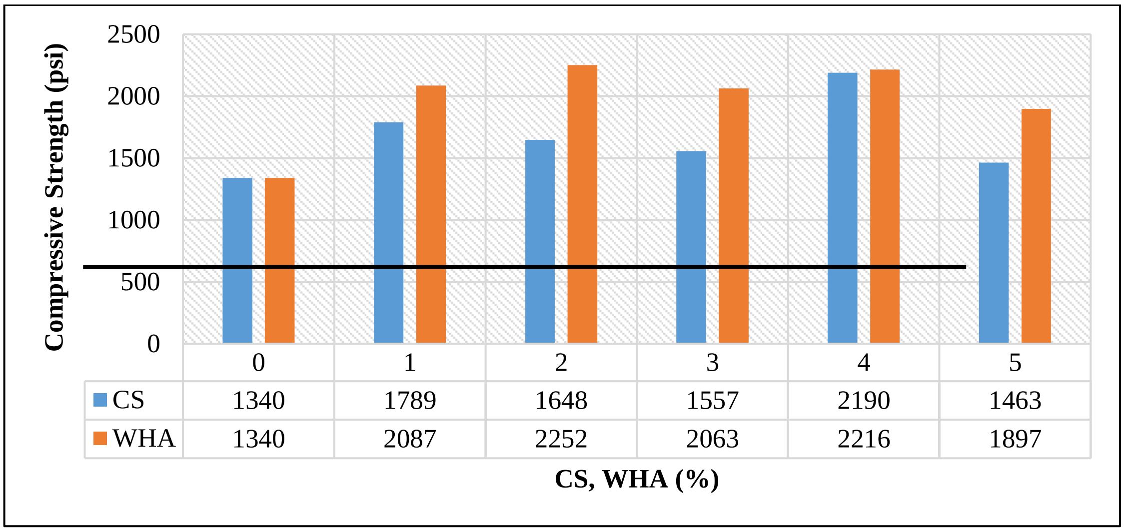

Fig. 12 Effect of CS and WHA on Compressive Strength at 140 °F at Atmospheric Pressure for 12 hrs

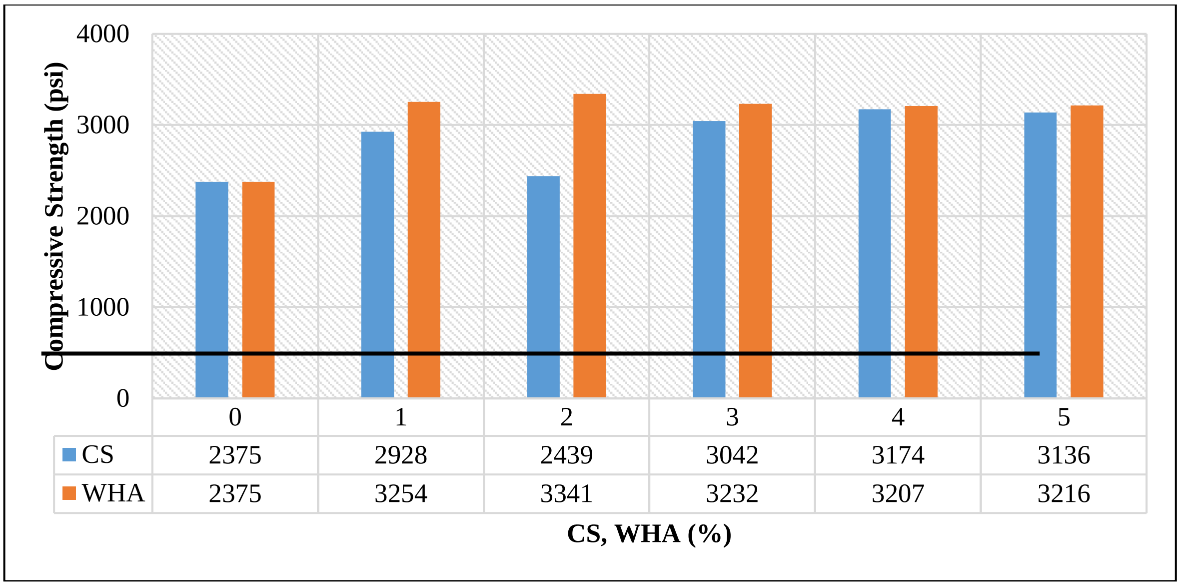

Fig. 13 Effect of CS and WHA on Compressive Strength at 140 °F at 3000 psi for 24 hrs

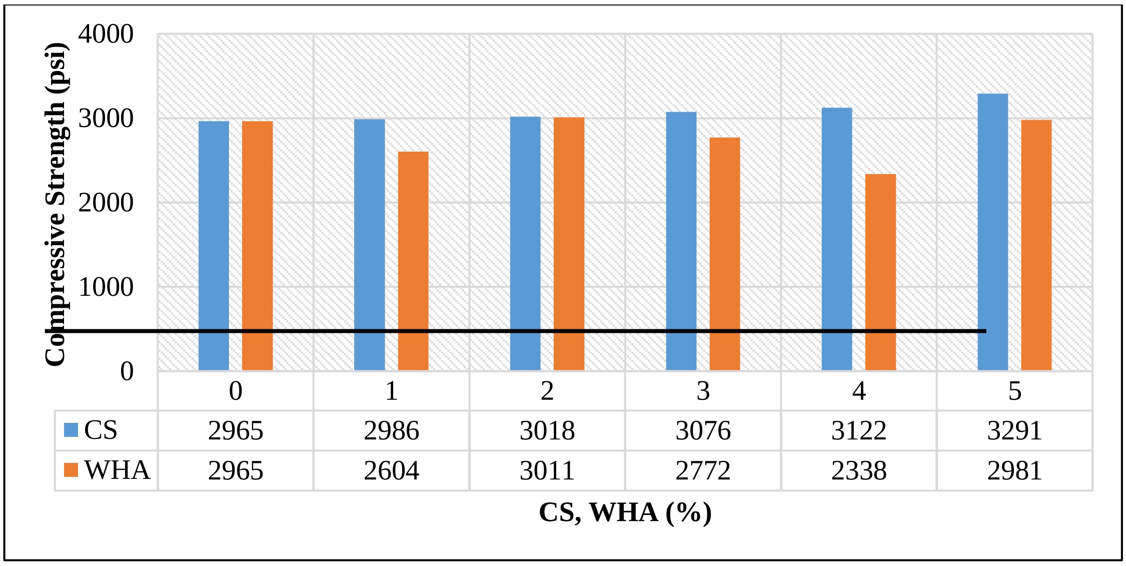

Fig. 14 Effect of CS and WHA on Compressive Strength at 170 °F at 3000 psi for 24 hrs

pH Test

The pH test was conducted to analyse the acidity of alkalinity of the cement slurry in various concentrations as shown in Table 4 and Fig. 15.

Table 4 pH Test of Slurry Samples

pH Test						
Additive	**0**	**1%**	**2%**	**3%**	**4%**	**5%**
CS	11.9	11.9	11.9	11.9	12	12.1
WHA	11.9	12	12.5	12.4	12.3	12.1

Corrosion is one of the problems in oil well drilling and it is one of the reasons why cementing is done to prevent corrosive fluids from getting into the wellbore. As such, cement slurry should be devoid of acidic additive. The pH of the cement slurry indicates alkalinity in varying concentrations of CS and WHA. At a concentration of 2%, an optimum result was recorded where the WHA peaked at 12.5 before declining to lower values as concentration increased. The pH of WHA was higher than the CS and this could be as a result of the higher amount of Na_2O present in WHA (Table 2) since Na_2O is a strong base [19].

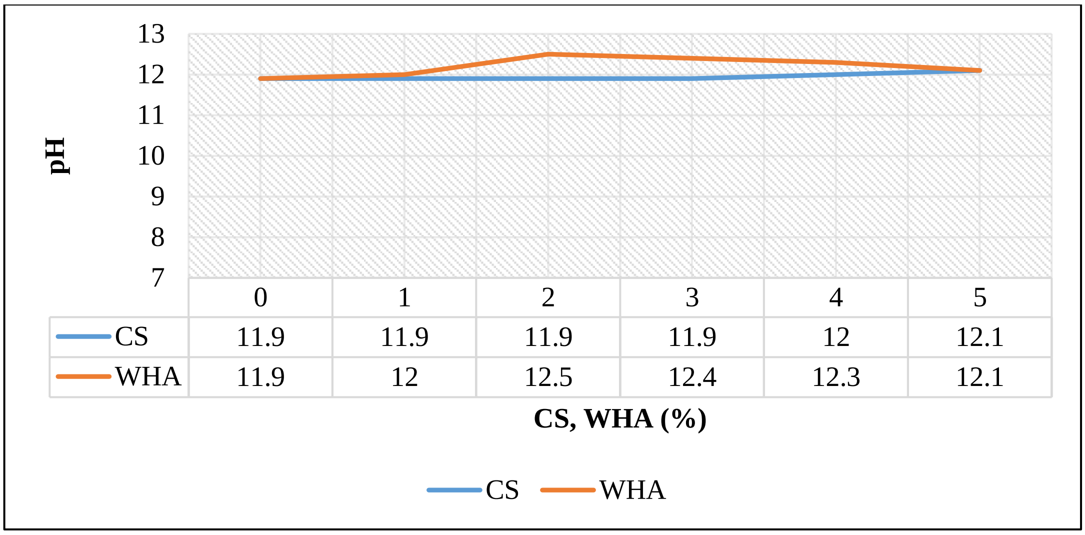

Fig. 15 pH of Cement Slurry in Varying Concentrations of WHA

Conclusions

From the research, it can be concluded that;

i. The locally manufactured cement and WHA compared favourably with the oil well class G cement for the various chemical properties tested;
ii. The WHA compared favourably with the CS used in the oil industry;
iii. The locally manufactured cement blended well with the WHA and the CS;
iv. For most tests conducted, an optimum result was obtained at a concentration of 2% for WHA added;
v. Although, the locally manufactured cement has short pumping time, the WHA further decreased the setting time thereby acting as an accelerator;
vi. The WHA and CS proved to have the minimum required cement strength of 500 psi per the industry practices after periods of 12 and 24 hrs;
vii. In terms of free fluid, all samples met the industry practice standard (less than 5.9%); and
viii. The plastic viscosity of all samples met the requirement of less than 100 cP for cement slurry to remain pumpable and yield point exceeded 15 Lb/100 ft^2 which prevents cement from settling making it pumpable.

Recommendations

Cementing in the oil and gas industry is expensive. It is estimated to be between 10% to 15% of the overall cost of the well depending on depth of well, size of well, type of cement used, amount of additives, Wait on Cement (WOC) time and the casing program [20]. To champion Ghana’s oil and gas local content policy implementation, it is recommended that;

i. Local Portland cement should be used for shallow wells cementation operation as well as WHA as accelerators instead of importing commercial accelerators. These will boost the local cement industry and help solve environmental issues surrounding water hyacinth to facilitate the activities of fishermen respectively;
ii. The economic analysis of the use of the Ash and local Portland cement should be done to establish the economic benefits;
iii. Further work could be done to know if WHA could enhance cement properties at temperatures above 170 °F.

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