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Experimental Investigation of Sheanut Shells Ash as Partial Replacement of Cement for Sustainable and Affordable Concrete Production

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Abstract: *Modern scientific and technological move towards concrete production is aimed at achieving sustainable and affordable concrete construction. This move has led to the search for non-conventional local supplementary cementitious materials (SCM's) including the possibility of using industrial and agricultural based pulverized and combustible wastes in concrete construction. In this study, an experimental investigation was conducted on the potential use of sheanut shells ash, derived from the combustion of sheanut shells – an agro-based waste, as partial replacement of cement in concrete. The cement content in the concrete mix was partially replaced 0%, 10% and 20% by mass with sheanut shells ash. The effect of the ash on setting time and workability were examined. Five concrete cubes were prepared for each of the replacement levels from which three cubes were randomly selected from each replacement level and tested for compressive strength at three stages of curing age (14, 28 and 90 days). There were high and minimal reductions in the compressive strengths of the experimental cubes over the control cubes at the 14 and 28 curing age respectively. However, there was a significant increase in strength of the experimental cubes over the control cubes at the 90 days curing age. Though the ash has an improved increasing effect on strength, the findings will limit it use in situations where long term strength development is required.*
Keywords: *Sheanut shells ash, partial replacement, setting time, workability, compressive strength*

I. Introduction

According to Abraham Maslow theory of motivation, one of the physiological needs of human beings is shelter. But any time the issue of shelter or housing is tabled for discussions by policy makers, terms like "housing deficit" and "housing inadequacy" dominate, but we actually live in a "housing desperate" world. Research findings indicate that people who live in developed countries are "housing rich" but those living in developing countries are "housing poor" and infact, "housing desperate" [1]. The global and national statistics are horrifying. In the global picture, it had been reported that more than 1000 million people throughout the world live in grossly inadequate housing while more than 100 million people have no housing whatsoever [2]. In the national front, it has been found that Ghana's housing deficit stands at an estimated number of 1.7 million units and is expected to double by the year 2025 if steps are not taken to address the situation [3].

The over dependence on conventional concrete materials, especially cement, which raw materials are mostly imported, in concrete and mortars for housing in developing countries is largely responsible for the continuous increase in housing cost. The importation of clinker and gypsum alone for the production of Portland cement, used extensively in Ghana, costs the nation not less than 180 million US Dollars annually [4]. Therefore, it is advisable for developing countries to take cost and content of cement in concrete into consideration and develop new technologies that would employ the use of local based supplementary cementitious materials (SCM's) through research to facilitate the provision of sustainable and affordable concrete construction [4].

These supplementary cementitious materials according to Thomas (2002) include all pozzolans and hydraulic materials that contribute to the properties of concrete through pozzolanic or hydraulic activity, or both when used in conjunction with cement [5]. Pozzolans are defined as siliceous and aluminous material which do not possess cementitious property in itself, but reacts in the presence of water with the lime at the normal temperatures to form compounds of low solubility having cementitious properties [6]. Pozzolanic supplementary cementitious materials that are commonly used in concrete production are fly ash, silica fume, calcined clay and volcanic ash, while those SCM's that are hydraulic in behavior are ground granulated blast furnace slag and fly ash with high calcium contents [5].

In the olden days, the use of SCM's as partial replacement of cement in concrete production to save cost and modify some properties to suit specific requirements in some ancient civilized countries had been reported. Historical reports indicate that the Romans added volcanic ash to concrete to save cost and also allowed it to set under water while the Egyptians added horse hair and animal blood to concrete to make it less liable to crack while it hardened and also to make it more frost resistant [7]. The potential use of fly ash in concrete has been known almost since the start of the 19th century [8], although it was not until the mid 1900s that significant utilization of fly ash in concrete began following the pioneering research conducted at the University of California, Berkeley [9].

Presently, the use of SCM's in concrete production is geared towards the utilization of local based industrial and agricultural by-products in the interest of providing sustainable and affordable concrete construction to satisfy the housing needs of majority of the poor in developing countries [10], [11], [12] and [13]. The concept of sustainable and affordable concrete construction was introduced in the UK where the government sponsored many research projects concerning environmental issues, reduction in waste, use of industrial and agricultural by-products, as well as recycling products of demolition. Sustainable and affordable concrete construction is the prudent use of natural materials as constituents of concrete, so that they remain available for future generations and be affordable to meet their housing needs. The increased in the awareness of this principle has led to more research work aimed at optimum and prudent use of cement and its total or partial replacement with by-products such as fly ash, blast furnace slag, etc [14]. It is in pursuance of this principle that an attempt is made in this paper to investigate the pozzolanic reactive effect of sheanut shells ash (SSA) as partial replacement of cement on concrete setting time, workability and compressive strength.

Sheanut shells ash (SSA) is an agro-based by-product derived from the combustion of sheanut shells as a way of waste disposal during the processing of shea butter which is one of the most commonly used food hydrocolloids in Ghana. The butter has many uses and applications; the matured fruit is edible and as such eaten as a fruit; when refined, the oil is used for cooking, frying and even as a substitute for the more valuable dairy butter. Due to its exceptional healing qualities, it is used globally as a body lotion, scalp and hair applications; for high quality cosmetics and quite recently, in the aromatherapy industry [15]. The commercial use of the shells and the shells ash has not been explored except that the ash is soaked and the soaked water squeezed out, and used locally in making soap for washing and bathing purposes. The shea tree grows mainly in tropical savannah regions of Africa and South America. Ghana produces about 200,000 tonnes of sheanuts annually and according to [16] is the leading producer in the world followed by Burkina Fasso, Ivory Coast, Togo, Mali, Benin and Nigeria in that order. Hence, the availability and affordability of the burnt shells ash in the study area is guaranteed.

II. Materials and Methods

2.1 Materials Used

Sheanut shells ash (SSA) was used in this study as a supplementary cementitious material to partially replace the cement content in the concrete. The ash was obtained from a local shea butter extraction waste dumping/burning site at Fielmuo near Nandom in the Upper West Region of Ghana. Good quality natural river sand and stones of up to 30mm nominal maximum size, sourced from a local construction site were used. Tap water with the quality conforming to BS 3148: 1980, available in the laboratory supplied by the Ghana Water Company Limited (GWCL) was used for all mixes [17]. Finally, "Ghacem", a commercial ordinary Portland cement brand produced in Ghana in conformity with BS 4027: 1986 specifications for Portland cement was used [18].

2.1.1 Sheanut Shells Ash Chemical Analysis

The sheanut shells, for the purpose of this study refer to the outer hard covering of the nut (Fig 1). The shells were subjected to control burning in the open air amidst constant turning up with a long metallic rod with wooden handle, to ensure even combustion so as to improve the ash pozzolanic properties as recommended [19]. The ash was left to cool and was sieved through a 325 mesh 45μm sieve to eliminate any un-burnt and other unwanted matter from the fine powdered ash (Fig 2). The fine ash was parceled and sent to the Agro-Forestry Department Laboratory of the Kwame Nkrumah University of Science and Technology, Kumasi, where the chemical analysis was done using different methods as a guide with focus on pozzolanic and hydraulic reactive properties.

Figure 1: Sheanut Shells

Figure 2: Sieved Sheanut Shells Ash (SSA)

2.1.2 Aggregates Characteristics

The aggregates quality and suitability properties were investigated at the Wa Polytechnic Building Technology laboratory. The sampling and testing were carried out in accordance with requirements of the appropriate parts of the BS 882: 1992 [20]. The following characteristics were studied; specific gravity, water absorption, fineness modulus, abrasion, flakiness index and elongation index.

2.2 Setting Time

Cementing materials in concrete mixes are expected to retain their plasticity for at least 30 minutes from the time water is mixed to it [21]. The impact of ashes including fly ash on the setting behavior of concrete has been studied. It has been found that high calcium ashes generally retard setting to a lesser degree than low calcium ashes, probably because the hydraulic reactivity of ash increases with increasing calcium content [5]. Therefore, the test is meant to study the effect of the ash used on the setting behavior of the concrete.

The cement content in the test specimens was replaced 0%, 10% and 20% by mass with an equal mass of sheanut shells ash (SSA) and labeled as A_0 (control specimen), B_{10} and B_{20} (experimental specimen). The water content needed to prepare the cement and SSA content test blocks to obtain the desired consistency for the setting time test was determined through the standard consistency test using the Vicat apparatus in conformity with BS 4550 – 3.5 specifications for the determination of standard consistency [22]. The test blocks were made with the appropriate cement/SSA/contents and the required amount of water for each replacement level. The blocks were then tested for the initial and final setting times using the initial set and final set needles respectively in the Vicat apparatus in accordance with BS 4550 – 3.6 specifications for setting time test [22].

2.3 Workability Measurement

The effect of carbon contents in fly ash and other ashes on fresh concrete workability has been investigated. Research findings indicate that finer and low carbon content ash reduces the water demand of concrete while coarser and high carbon content ash increases the water demand. It is therefore recommended that each 10% of ash content should allow for a water reduction or increase of at least 3% depending on the fineness or coarseness and carbon content [5].

The slump testing method was used because of its simplicity and suitability for concrete mixes of medium to high workabilities (25 – 125mm slump) using stones of up to 30mm nominal maximum size. The preparation of the mix for the slump test was performed in accordance with BS 1881 – 125: 1986 specifications for fresh concrete in the laboratory [23]. The required quantities of the materials for the mix were batched by weight. Trial tests were conducted on concrete mixes with varied water contents in order to obtain an optimum water content to produce the normal mix (A_0) with a true slump. A water/cement ratio of 0.5 recorded a true slump and was used for the normal mix (A_0). The SSA is coarser and has a high carbon content of 4.25 (Table 4), hence a 5% increase of water content was allowed for at each replacement level. Therefore, a water/cement/SSA ratio of 0.53 and 0.56 were used for the experimental mixes B_{10} and B_{20} respectively. The mixing was done by hand in a clean head pan. The cement, sheanut shells ash (SSA) and sand were first mixed in a dry state until they were thoroughly blended before the stones were added and the entire mixes turned severally until the stones were uniformly distributed in the mix. Water was then added in two phases while the mixing continued until a uniformed colour and desired consistency was achieved. The slumps for all the mixes were measured using the slump cone.

2.4 Compressive Strength

The effect of partially replacing a certain mass of cement with an equal mass of low calcium fly ash has been established. Studies found that as the level of replacement increases the early age strength decreases. Long term strength development is improved when ash is used and at some age the strength of the fly ash concrete will equal that of the cement concrete so long as sufficient curing is provided. Sufficient moulds measuring 150 x 150 x 150mm were available in the laboratory to enable all the cubes to be cast from the same mix in the same day. This was aimed at eliminating discrepancies such as variations in temperature, water content, mix proportion and compaction, which might have arisen if more than one day was used to cast the cubes. The cubes were removed from the moulds the next day and marked A_0, B_{10} and B_{20} for the 0%, 10% and 20% cement/SSA contents replacements levels respectively and submerged in water for curing. Three cubes from each replacement levels were randomly selected from the curing water after 14, 28 and 90 days of submission and tested for the 14, 28 and 90 days compressive strength using the compression testing machine (Fig 3).

Figure 3: Concrete cube being crushed

III. Results and Discussions

3.1 Sheanut Shells Ash Chemical Compounds and Contents

The calcium, silica, aluminium, and carbon contents have been found to be the best indicators of how the ash will behave in concrete, although other compounds such as iron, sulphate, magnesia and many others can also affect the ash performance. The calcium content is useful in predicting how effective the ash will be in terms of reducing the heat of hydration [24], controlling expansion due to alkali-silica reaction [25], and providing resistance to sulphate attack [26]. Suitable percentage ranges and limits for compounds in ash for concrete production have been established. Previous studies recommended the following ranges; calcium 1 – 8%, silica 30 – 60%, aluminium 15 – 30%, carbon 1 – 30% [6]. It has also been reported that low calcium fly ash (< 8%) are pozzolanic and display no significant hydraulic behavior [5], the ASTM C618 specifications for fly ash indicated that in addition to having pozzolanic properties the ash also has some cementitious properties if the sum total of the percentages of the oxides (silica, aluminium and iron) is equals to or greater than 50% [27]. In Table 1, the results of the chemical analysis of the sheanut shells ash (SSA) are presented. It could be noticed that the calcium content is 1.81%, far less than the 8% limit. Again, the total sum of the oxides (S_i0_2 + Al_20_3 + Fe_20_3) is 50.19%, slightly exceeding the 50% minimum limit. Thus, the SSA used in the study has both pozzolanic and cementitious properties and may display no significant hydraulic behavior.

Table 1: Chemical Properties of SSA

Compounds	Symbol	Results (%)	Test Method
Calcium	Ca0	1.81	EDTA Titration
Silica	S_i0_2	29.01	Gravimetric
Aluminium	Al_20_3	20.05	spectrophometric
Carbon	LOI	4.25	Gravimetric loss of weight on ignition
Iron	Fe_20_3	1.13	Spectrophometric
Magnesia	Mg0	1.48	EDTA Titration
Sodium	Na_20	0.26	Flame photometric
Potassium	K_20	1.7	Flame photometric
Phosphorus	P_20_3	0.29	Spectrophometric

3.2 Aggregates Characteristics

The characteristics of the natural river sand and stones used in this investigation, determined using the British Standards are presented in Table 2.

Table 2: Characteristics of the Aggregates used

Test conducted	Stones		Sand	
	Results	BS Limits	Results	BS Limits
Bulk specific gravity	2.60	2.6 – 2.75	2.61	2.6 – 2.75
Apparent specific gravity	2.68	2.6 – 2.75	-----	------
Water absorption	1.96%	20% max	11.6%	20% max
Fineness modulus	7.0	5.5 – 8.0	3.26	2.0 – 3.5
Abrasion strength	25.6%	40% max	------	-------
Flakiness index	12%	15% max	------	-------
Elongation index	9%	10% max	------	-------

3.3 Setting Time

Fig 4 presents the results of the setting time test conducted. There is a steady increase of setting time from A_0 to B_{20} for the initial and final setting times. The calcium content present in the SSA is low and as such this outcome is expected because hydraulic reactivity in ash decreases with decreasing calcium content.

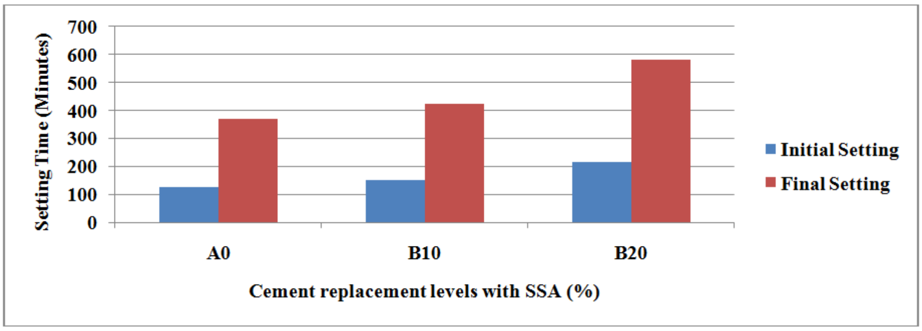

Figure 4: Setting behavior of SSA content in fresh concrete mix

3.4 Slump Test

The slump test results are given in Table 3 and Fig 5. The values indicate a steady decrease of slump from 115mm for A_0 to 57mm for B_{20} even though the water content was increased by 5% at each replacement level. This is an indicative that SSA is coarse with high carbon content, hence the higher the SSA in the mix, the more the water content required to achieve a true slump.

Table 3: Slump Test Results

Mix	W/C Ratio	Slump (mm)	Collapse height (mm)	Degree of workability
A_0	0.50	115	185	High
B_{10}	0.53	82	218	High
B_{20}	0.56	57	243	Medium

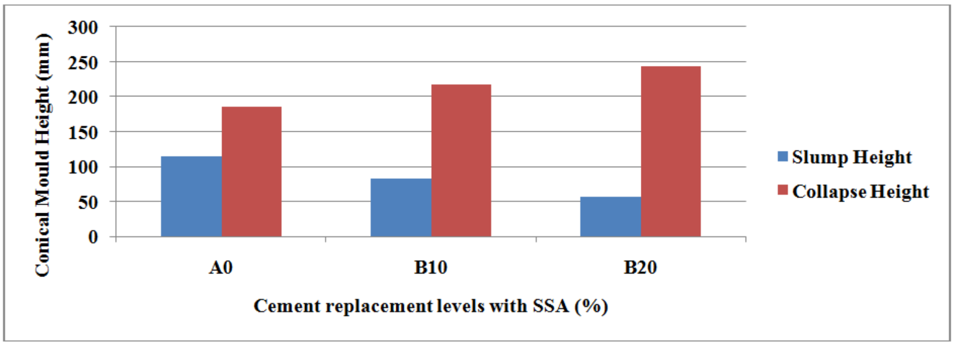

Figure 5: Slump behavior of SSA content in fresh concrete mix

3.5 Compressive Strength

The compressive strength test results are given in Table 4 and the effect of curing age on long term strength development presented in Fig 6. Early age compressive strength is reduced as the SSA content increases.

Table 4: Compressive Strength of Concrete Cubes (N/mm^2)

Cube	14 days		28 days		90 days	
	Values	Mean	Values	Mean	Values	Mean
A_0	18.71 18.58 19.02	18.77	23.16 22.13 22.53	22.61	26.76 27.29 26.13	26.73
B_{10}	14.98 15.16 14.13	14.76	19.87 19.44 20.13	19.81	33.78 32.98 34.49	33.75
B_{20}	9.82 10.80 10.49	10.37	17.42 16.93 17.96	17.44	30.31 29.33 30.36	30.00

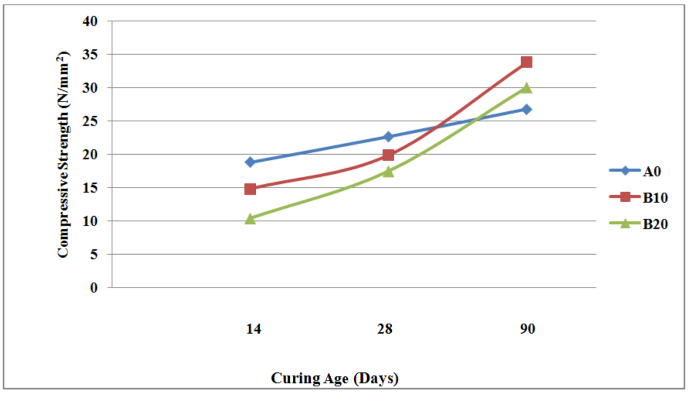

Figure 6: Effect of curing age on compressive strength

A high reduction of strength of 21% and 45% was observed for the B_{10} and B_{20} respectively over the A_0 at the 14 days curing age. The reduction in strength narrowed to a minimum of 12% and 23% for the B_{10} and B_{20} respectively over A_0 at the 28 days curing age. However, there was a significant increase of strength of 21% and 11% for the B_{10} and B_{20} respectively over A_0 at the 90 days curing age (Figure 6)

The mean compressive strength values for A_0, B_{10} and B_{20} at each curing age (14, 28 and 90 days) were compared using a One-Way Analysis of Variance (ANOVA) at a confidence interval of 95%. A high level of variability between the individual cement/SSA content replacement levels existed in all the three curing ages (Table 5). The ANOVA results therefore suggest that there is a statistically significant difference in the compressive strength among the replacement levels in all the curing ages.

Table 5: Summary of ANOVA Results – Compressive Strength (N/mm^2)

	Cubes curing and testing ages (days)		
	14	28	90
N	9	9	9
Missing	0	0	0
F – value	262.745	81.805	89.266
P – value	0.000	0.000	0.000

Significant at 0.05 (P – value)

IV. Conclusions

The findings from the chemical analysis suggest that SSA possesses both pozzolanic and cementitious properties, with very little or no significant hydraulic properties since the sum total of the oxides is slightly greater than 50% as specified in ASTM C618 – 05. More time is required for SSA content concrete cubes to set because of it low calcium content. Therefore, other chemical additives could be added to reduce the setting time in situations where speedy work is required. SSA is coarser in nature with high carbon content and therefore, will require more water content at higher replacement levels to achieve a true slump. The short term compressive strengths of cement/SSA content concrete cubes were reduced whiles the long term strength was higher than normal concrete at the 90 days curing age.

It is therefore concluded that SSA is a potential supplementary cementitious material (SCM) for concrete construction in a bid to save the cost of materials in concrete production. Sheanut shells ash (SSA) can be used in situations where long term strength is required. The wide search for cheap and local alternative industrial and agricultural based waste materials as supplementary cementitious material for sustainable and affordable concrete construction will enhance and promote the adoption and use of SSA as partial replacement of cement in concrete.

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